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VOLUME ONE
PROJECT 9015
FINAL REPORT
1960 - 1964

June 1965

ABSTRACT

An Image Processor has been designed and built as a portion of a coherent high resolution radar system. This unit is an optical device designed for use in a laboratory on the ground. The Processor accepts the (unintelligible) data from the airborne equipment and converts it to a radar "map." A separate chemical processor is used to develop the data and map films.

This report, along with a Final Report on the Processor, covers all aspects of the program from its inception in 1960 to its conclusion* at the end of 1964. The work included initial studies, the design and construction of the Processor, the test and modification program, the operation of the unit in support of the coherent radar system, and many ancilliary studies.

The report is published in two volumes, the first is the description of the project, the second contains several detailed engineering analysis and other appendixes.

*Certain field support activities and studies will run into 1965.

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Section 1.0

INTRODUCTION

1.0 INTRODUCTION

The Itek Corporation has designed and built the Model 9015 "Image Processor" shown in Fig. 1. This Processor is a portion of the coherent high resolution radar system AN/APQ-93*. The Processor was designed in 1960-61, built in 1961, improved in 1962 and 1963, and has been used to support various test programs since the beginning of 1962.

The radar system was intended to advance the state-of-the-art by an order of magnitude, a challenging goal for a three year program. The performance of the system, although not quite as good as the initial goals, is as good or better than any current system known to us. The "azimuth" performance normally achieved on flight test films is 10 foot ground resolution, and laboratory correlation has achieved 5 foot resolution.

The program was initiated with the intent that the equipment could be quickly built and would be operating reasonably near the design goals after only a short shake-down period. This intent was implemented by a design philosophy which emphasized simple techniques that could be predicted to work with the greatest degree of confidence. Weight, cost, flexibility, and ease of operation were not ignored, but were secondary considerations.

*The airborne radar electronics and antenna were built by the Westinghouse Corporation. The airborne recorder was built on a separate project by Itek on subcontract to Westinghouse.

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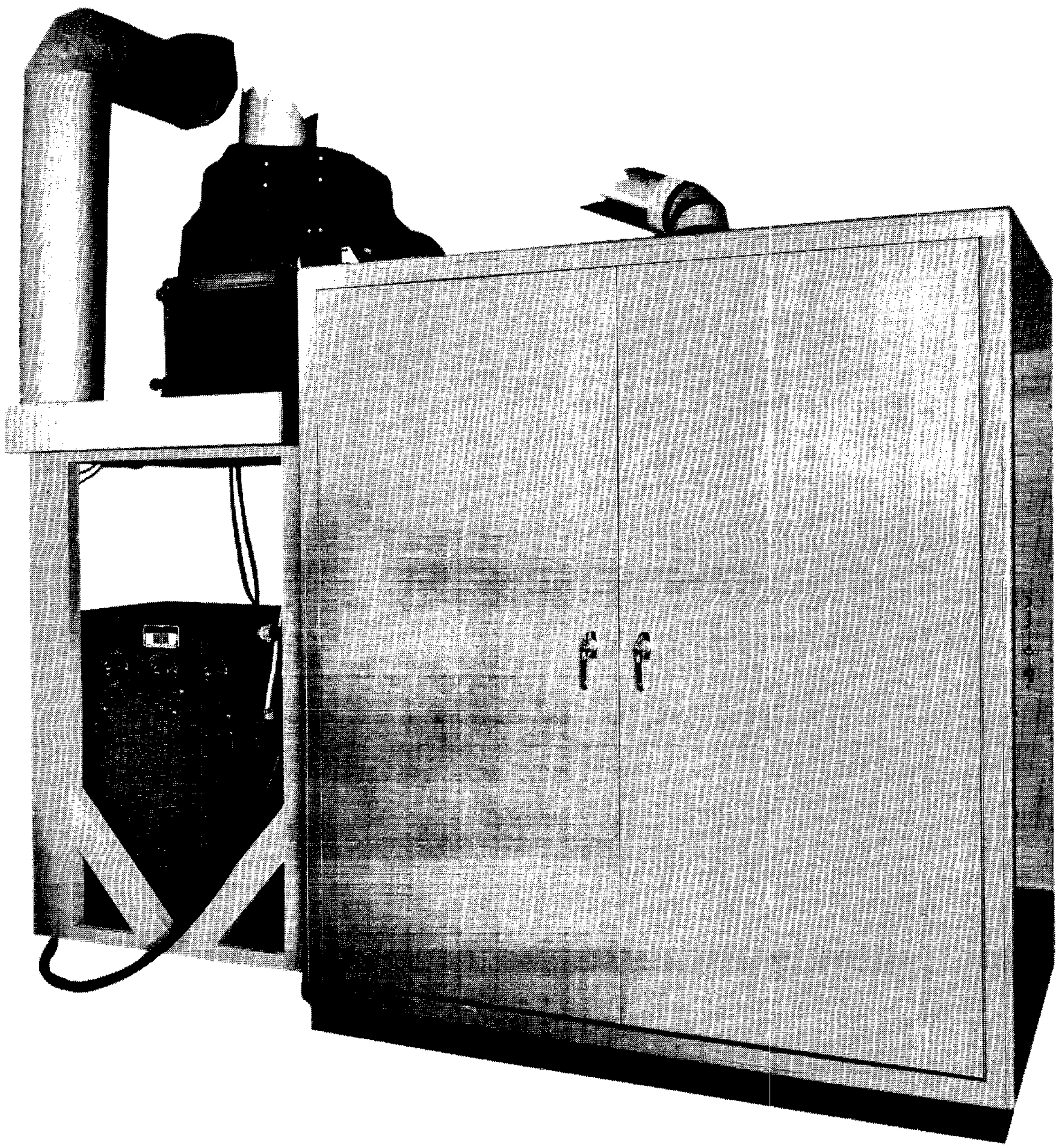

Figure 1

9015 Processor

This is a rear view of the cabinet which houses the optics and film drives. The cabinet is approximately 6 feet high. The carbon arc is shown on the left, the exterior control panel is at the right. An interior front view is shown in Fig. 5, other views are included in reference 1.

During the course of the system program various problems were encountered in series, and the treatment of these lead into a three year program. Some of the problems have been corrected by more sophisticated designs, some by the application of new knowledge, and some are not yet satisfactorily corrrected. Many of the remaining problems can be corrected by techniques which have been developed, but they are expensive and have not been implemented as of now. The Processor is adequate to support the system test program at the present time.

This report describes all phases of the $4\frac{1}{2}$ year program except the construction of the Processor, which is covered in the Model 9015 Processor Final Report published in May 1964. The appendixes contain a substantial amount of detailed engineering analysis on subjects directly related to the project. Some of these appendixes have been previously published and some are appearing in published form for the first time. Section 7.0 of this report presents material which has not been previously reported. Of particular interest is Section 7.5, which describes some investigations relating to the potential usefulness of the output radar map.

This report covers the period from the inception of the program in 1960 up to the end of 1964. The final editing was done in June 1965, and a few remarks and additions were made at that time to bring the text in agreement with the latest knowledge. However, this report does not describe the work done in 1965.

1.1 Purpose of the Processor*

The Processor is an integral part of the coherent radar system shown in

*The word Processor will be used in this report to indicate the device shown in Fig. 1. The word correlator will be used to include all optical correlators including the bench correlator and the Processor. The name Processor is not to be confused with the common terminology as the name for a device that chemically processes a film.

Fig 2. The airborne system is designed to detect and record the phase and amplitude of the return signals. This technique collects the data which is necessary for a high resolution in the azimuth direction, but the data is unintelligible as recorded, see Fig. 3. The data is stored on photographic film which is then returned to the ground station for chemical developing. The film is inserted into the Processor which "processes" the data into an intelligible high resolution radar map as shown in Fig. 4. This map film is the end product of the radar system. It is also possible to insert the data film (or a duplicate of the data film) into a "detail correlator" which presents a correlated map of any small area directly on a viewing screen.

The Processor is designed to accept and properly "decode" or process the data generated by the associated radar unit. It does not require any additional inputs, although the system could be designed such that certain flight parameters would be recorded and used to control adjustments in the Processor. This Processor will not handle the data from any other known coherent radar system, although it could be modified for other systems which use film as the basic storage medium.

1.2 Historical Summary of the Project

The project began early in 1960 when [redacted] STAT asked Itek and Westinghouse to consider building a coherent radar system.

STAT Representatives of [redacted] considered the technical problems in proposal studies and joint meetings during the Spring. They decided that the system could be built. The technical approach and plan of work was presented to the customer [redacted] which called for a flight test

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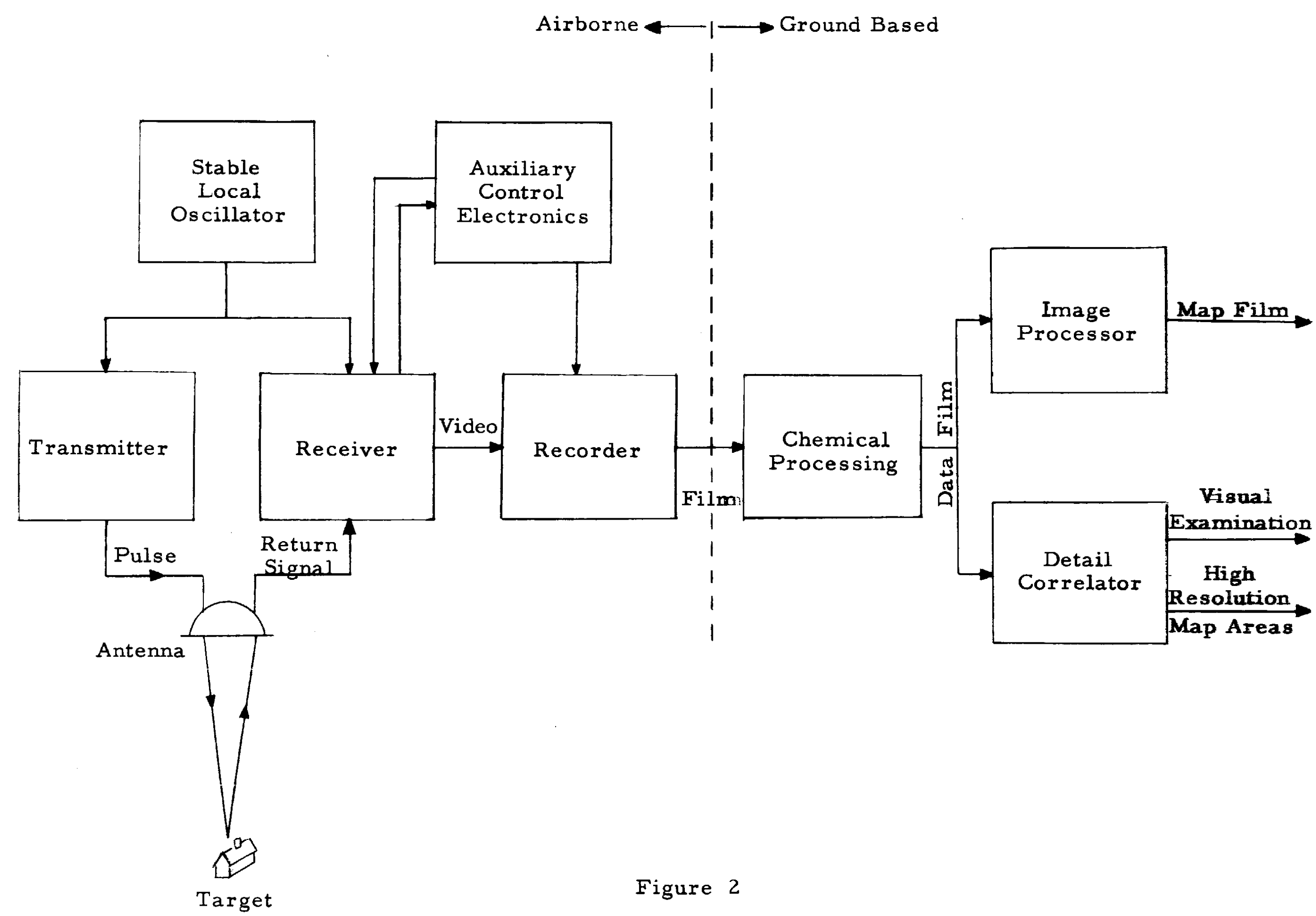

Figure 2

Block Diagram of Coherent Radar

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Figure 3

Sample Data (Input) Film

This is a positive duplicate of a section of the film from flight S87.

Note: In order to display a good example of the Flight Film data and also give a good impression of the format, the data blocks from run S93 have been dubbed onto the S87 film (the data flash was turned off in the S80 series, the S90 series is a shakedown of a new radar set).

The clock and data card are repeated at approximately 12 inch intervals (about 10 second between flashes in the recorder). The nearest range is at the top, the furthest range is at the bottom. The gap in the center is due to an optical offset in the recorder, the actual ground data lost can be very small (see Appendix II of the Processor Final Report for details).

The short horizontal lines spaced approximately an inch apart in range are reference range marks made every 9.8μ sec from the transmitted pulse.

The format is given in reference 1, Fig. 6.

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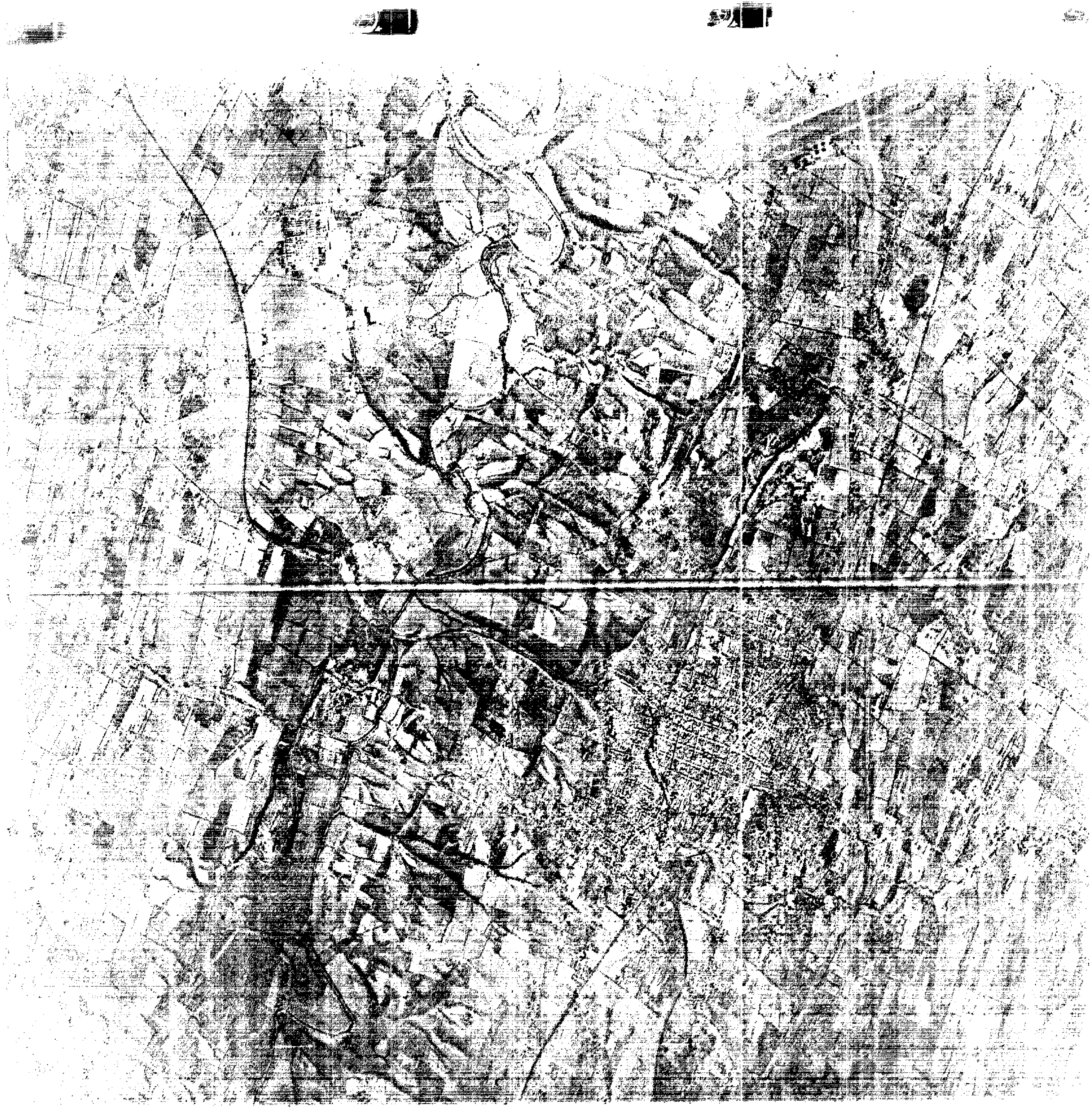
Figure 4

Output Print

This is a contact print made from the correlation of the data of Fig. 3. This is made from the near range half of Fig. 3, it is enlarged 2X in the range direction. In azimuth it is reduced 4.3X, so it is made from over 2 feet of data film.

The area shown is Martinsberg, West Virginia. The scale is about $1\frac{1}{2}$ inches = 1 mile. The airport is south of the town, and a large V.A. hospital is near the road east of the airport. The dark range reference marks can be seen north of the hospital. The streak along the center is due to a joint in the interference filter (see Page 39 and 40 in the Processor Final Report).



demonstration late in 1961. That proposal included the ground based image processor which is the subject of this report.

The Processor program was initiated upon receipt of authorization on 4 August 1960 and assigned Itek Project No. 9015. The staffing of the project began immediately. The first engineer started the experimental program to obtain the information required for the detailed design. By November most technical aspects were understood well enough to proceed with the basic design. The schedule of events in the construction of the Processor is shown in Table 1.

A set of guiding specifications were written for each subassembly in December. In February 1961 over 25 engineers, designers, and draftsmen were at work. At that time a detailed production schedule indicated completion by the end of August. During the winter and spring a number of design features were checked with breadboard models where feasible. Considerable attention was given to the optical design, optical mountings, and film drive. The basic design of most subassemblies was complete in May and a design review was held with the customer's technical representative on 16 May 1961.

The fabrication and assembly proceeded rapidly during the summer of 1961. It was expected that the unit would be finished in August, but a number of minor assembly problems and parts shortages arose to delay completion. The project did not go on an overtime crash basis since the vendors for some essential optical parts were behind schedule.

The basic unit was essentially complete* in October. It was aligned and adjusted during November and a preliminary acceptance test was run.

*The optical recording system to transfer the clock and data card to the output film was not complete.

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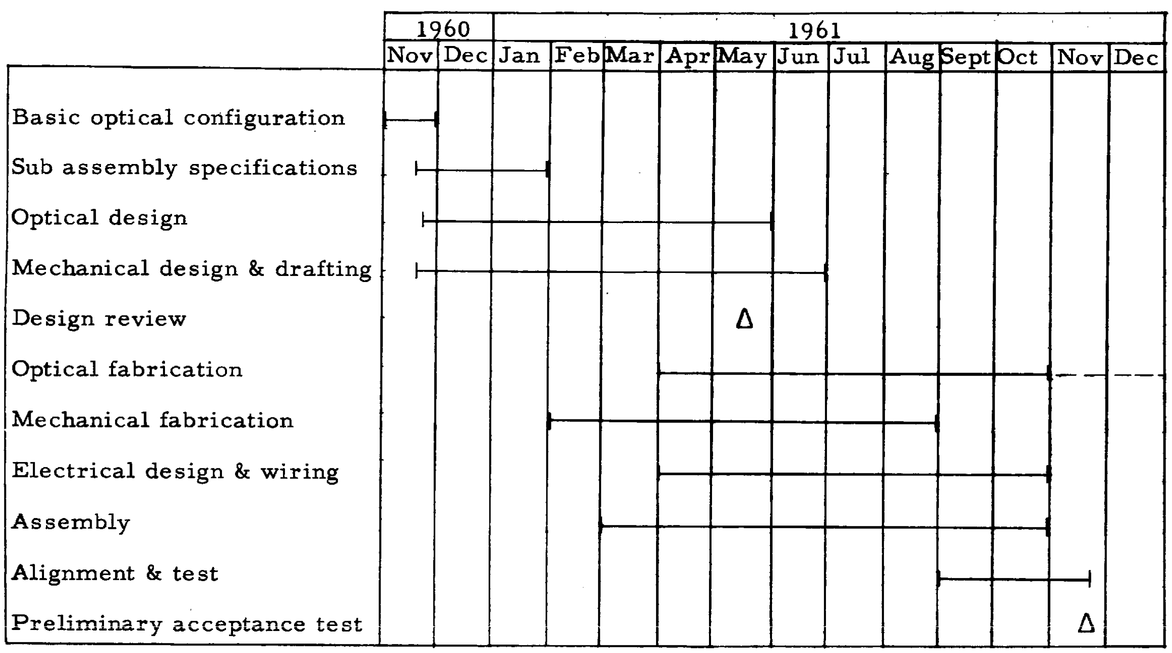

Table 1

Construction Schedule of Processor

This is an approximate schedule for the Processor as originally built. The end dates indicates about 90% complete.

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The early correlation experiments had shown the need for simulated input data and extensive testing to determine the characteristics of this new device. While the fabrication proceeded during the summer a Test and Simulation program was proposed and work was started to make simulated targets. This testing program gradually expanded until it represented the bulk of the effort by January 1962.

In February 1962 the optical system and film drive were modified to accept longer focal length targets on the data film. The unit was used to process the first F101 flight films in March, and a recognizable radar map was obtained from Flight S11 in May 1962.

The Test and Simulation program proceeded rapidly during the first five months of the year. At the end of May all testing that could be done with the old cylinder lenses was complete. It had been hoped that new lenses would be available by the end of May, but technical difficulties delayed delivery of a complete set of cylinder lenses until November. During the summer and fall, sixteen F101 flight test films were processed, a number of improvements were made in the mechanical parts of the Processor, and the first draft of a handbook and final report were written.

The installation of new cylinder lenses and the ten inch wedge interference filter in November 1962 brought new effort to improve the performance test results and the quality of the F101 flight test maps. This effort gained some immediate improvements and a report on the Test and Simulation program was written.

It was soon realized that further theoretical and experimental work was needed to fully integrate the Processor into the overall radar system. The

Processor had been designed for routine operational use and was poorly adapted for the continued testing, adjusting, and modifying that had occured in 1962 and probably would continue throughout the development program. Furthermore, many of the provisions for routine operation were no longer adequate due to the difference between original assumptions and actual operation.

A number of modifications were incorporated into the Processor during 1963 to eliminate most of the problems. They included a viewing station with a 4 x 5 camera back (February), a TV remote viewing capability (installed temporarily in March and completed in October), a new zero order stop in the relay lens (April), a new liquid platen with film guides (July), a new film drive (August), and a new data optics system (December).

The overall testing program continued to obtain better performance data. The work was expanded to include system effects. Considerable theoretical and experimental work was done on both the Processor and Recorder* programs to obtain a better understanding of the system and improve the overall results. New precision simulated test targets were made to support the more exacting tests. An experimental Processor was built to support some of the tests, prove out new techniques and provide an emergency back-up for the Processor in the field.

The newly developed laser is the ideal light source for correlation and one was purchased for use on certain tests as well as to gain knowledge required for a second generation Processor. The basic designs for such a processor were formulated and have been kept up to date so as to keep the customer informed of potential technical advances.

*The airborne recorder was built by Itek on a separate project.

The on-axis performance of the optical system was tested and found to be near the diffraction limit. Efforts to improve the overall map film quality brought out two unforeseen optical problems, an optical bandwidth effect and a field curvature. The first effect caused a larger loss in resolution due to the wavelength band than was originally realized. The second effect was found to be due to two unusual optical effects in the relay and cylinder lenses. Each of these problems received considerable attention, but feasible solutions were found to require more time and money than was justified on the present Processor.

Stray light is a serious problem in the correlator. An extensive study was made of the sources of stray light and some improvements in stray light level were realized by making suitable modifications to the unit and procedures. Further improvements would require major changes and hence are recommended for the next correlator built.*

Two company sponsored programs also contributed to this project in 1963. The first was an experimental program to make simulated target data by hologram generation techniques. This work was implemented with the laser and succeeded in making and reconstructing good holograms. The second program was the development of a capability to fabricate cone lenses at Itek. A simple cone lens was fabricated and tested and found to be close to our requirements. It was concluded that a cone lens could be made when required.

A final acceptance test on the Processor and associated optical equipment was performed in December 1963. In the first two months of 1964 some tests were run which indicated a limiting resolution of less than .0007 inches (measured at the output film) for the Processor. The overall system resolved

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*Some new minor modifications are being considered.

targets spaced by 20 feet. Later in the year corner reflector targets spaced 8 feet apart were detected and recorded on the bench, and targets 10 feet apart were resolved on map films made in the Processor.

The Processor was shipped to [redacted] in March 1964. Itek STAT personnel set up and operated it. The unit was used primarily in support of the continuing F101 tests. A number of accurate measurements of field curvature, magnification, and film drive ratio were made. In November the Processor and personnel were re-located at the Westinghouse plant in Baltimore to be closer to the electronic engineers and the F101 test operation.

The effort in Lexington during 1964 was devoted to the writing of a final report on the Processor, support of other phases of the program, and specific studies. The Processor Final Report (reference 1) was written early in the year and published in May. There were no important changes made to the Processor after shipment, so that report is still correct. The bulk of this Project Final Report was drafted late in 1964.

The support functions included routine correlation of the F101 flight test films, engineering back-up of the field personnel, theoretical and experimental support of the overall program and of specific tests run at Baltimore, and the generation of proposals for further improvements and second generation equipment.

The studies included the investigations of variable density aperture weighting filters, the experimental and theoretical analysis of the field curvature problem and methods to correct it, the detection of moving targets and close analysis of the image structure obtained on the output map film.

Section 2.0

DESIGN AND CONSTRUCTION OF THE PROCESSOR

2.0 DESIGN AND CONSTRUCTION OF THE PROCESSOR

The production of the Processor was originally the only task on Project 9015. Its design and construction constituted the entire program for the first year and continued to be the major portion of the effort until the end of 1963.

The work on the Processor was described in full in a report written in May 1964 entitled "Final Report Model 9015 Processor" (reference 1). That report can be considered as part of this Project Final Report, and the reader is referred to it for a discussion of that phase of the project. The only changes to be made are as follows:

Page 4, Fig. 3	Refer to Fig. 6 of this report for an up to date photo.
Page 5, Fig. 4 Page 7, Fig. 6 Page 9, Fig. 8	Refer to the current log book for up to date data. (There are no major changes as of 6/1/65.)
Page 13, second paragraph	The results of these studies are given in Sections 3.0 and 5.0 of this report.
Page 21, second paragraph	For more detailed operational requirements, see Appendix IV of this report.
Page 29, Fig. 14	Refer to Fig. 6 of this report for an up to date photo.
Page 30, last sentence	See Section 7.7 of this report.
Page 49, second paragraph	At present one wheel is in use. It covers a $1\frac{1}{2}\%$ range and is adequate for present needs.
Page 50, end of page	Film mistracking had not been a serious problem in the field. This is due to the improved design, routine operation, and relaxed requirements.

The theory of operation is discussed in the "Processor Final Report", but a brief section will be reproduced here for ready reference.

Two front views of the unit are shown in Figs. 5 and 6. The former photograph shows the optical parts and film drives, but is obsolete in some details, the second photo was taken recently. The optical schematic is shown in Fig. 7. The carbon arc is focused by the condenser lenses onto the input slit (5 to 40 μ wide). The collimator forms the plane wavefront to strike the data film and the field lens refocuses the beam onto the zero order stop. This opaque baffle stops all the light except that diffracted into the real image by the zone plate pattern. A pattern in the platen will have formed a diffraction image at a distance of 150 inches (or 200 inches). This is reimaged by the field lens to a point about 2 inches from the zero order stop. The cylinder lenses refocus it onto the output platen. In the original design (for the 24" focal length patterns) one cylinder lens was used but two lenses are required for the 150" patterns to avoid mechanical interference with the mirror.

The wedge interference filter which selects the wavelength for each range must be located at or near a range focus. This occurs at the input platen and again at the output platen. The original design used a filter at the input platen, but the 150" targets demanded a 3 inch wide filter, which could not be fabricated. The filter was shifted to the output, where the width requirement is less than 2 inch. Unfortunately, the vendor had to make the 9 inch length by butting two 5 inch filters, which leaves a streak down the center of the output film (see Fig. 4). This can be eliminated whenever the vendor obtains suitable equipment and the cost is justified.

The optical system in the range direction is an enlarger which uses the

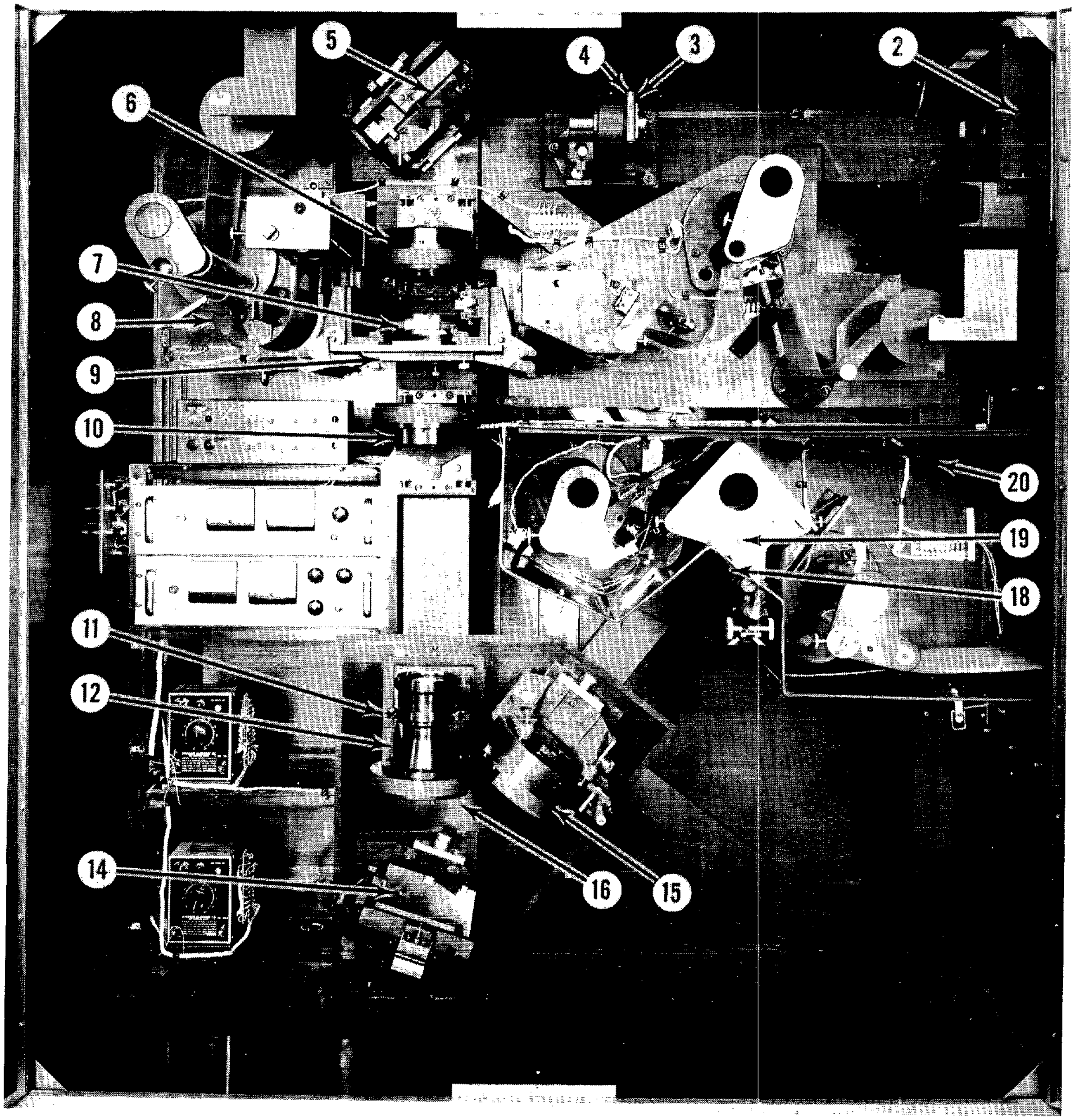


Figure 5

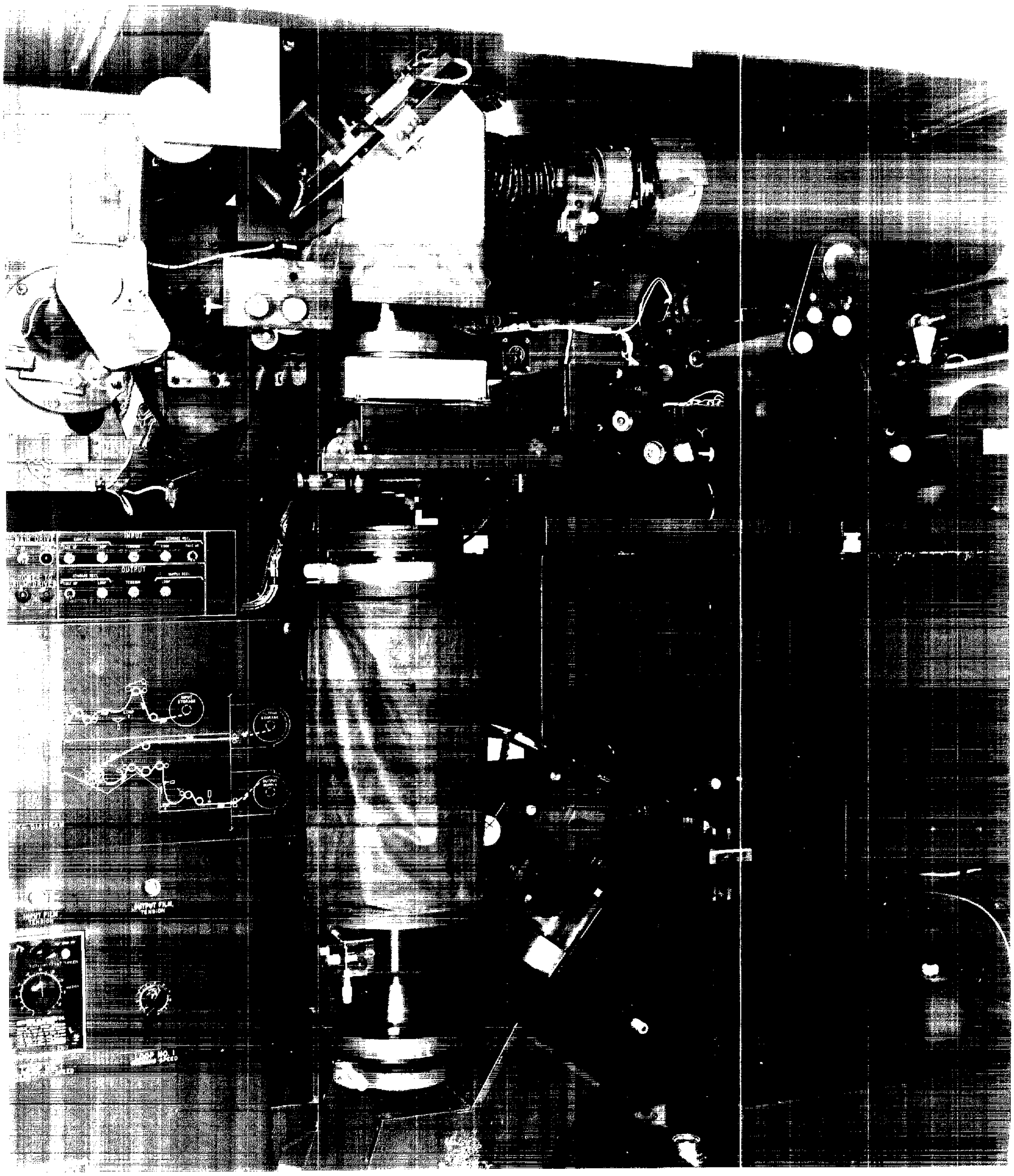
Processor-Optical Parts

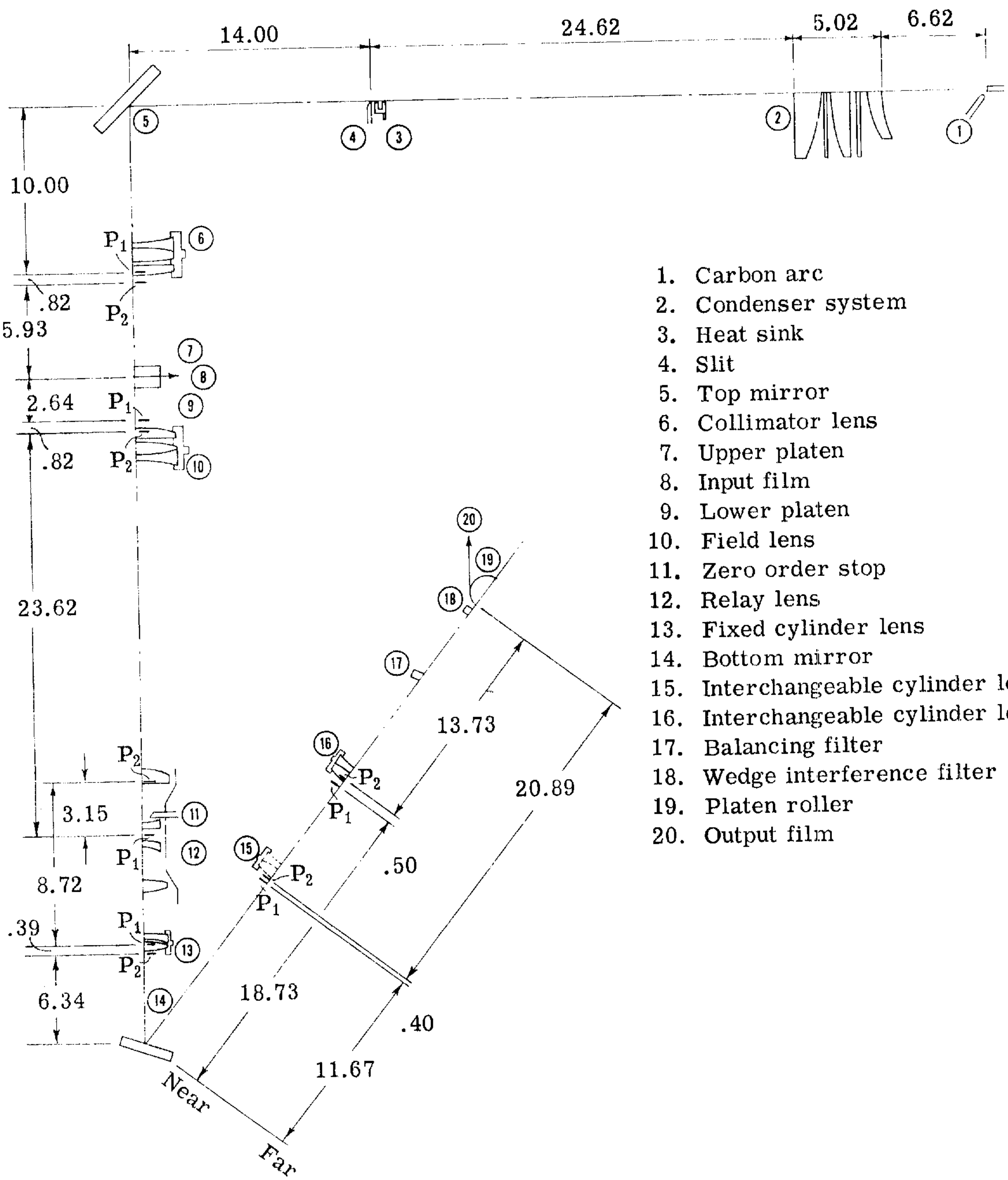
This is an early (1962) photograph of the interior of the Processor. The optical parts can be clearly seen and are identified by number (numbers are the same as those on Fig. 7). The film path can be followed by referring to the threading diagram seen in the next photo (Fig. 6). The function of the electrical controls can also be seen in Fig. 6.

Figure 6

Processor-Interior View

A recent (1965) photograph of the interior of the Processor. Many changes and additions have been made as can be seen by comparison with Fig. 5. The TV camera is at the lower right, its lens is looking upward toward the output image area.





1. Carbon arc
2. Condenser system
3. Heat sink
4. Slit
5. Top mirror
6. Collimator lens
7. Upper platen
8. Input film
9. Lower platen
10. Field lens
11. Zero order stop
12. Relay lens
13. Fixed cylinder lens
14. Bottom mirror
15. Interchangeable cylinder lens (far)
16. Interchangeable cylinder lens (near)
17. Balancing filter
18. Wedge interference filter
19. Platen roller
20. Output film

Figure 7

Optical Schematic

relay lens to magnify the range by a factor of 2. This magnification was originally chosen on the basis of using Plus X as the optimum film for achieving adequate resolution with the highest operating speed.

The exit slit is not critical, and merely limits the width of field used. The optical system forms an image about one half inch wide, the slit is usually set .100 inch wide. The width of the slit can be shaped to give a uniform exposure across the field if desired.

The performance of the Processor is discussed in Section 5.0 of the Processor Final Report. That discussion is still basically correct, except that experience and improved adjustments have given improved azimuth resolution. The following chapter covers this topic in further detail.

Section 3.0

PERFORMANCE OF THE PROCESSOR

3.0 PERFORMANCE OF THE PROCESSOR

The performance of the Processor and bench correlator cannot be simply specified independent of the overall radar system. During the course of the project the performance has been discussed and measured in many contexts ranging from a single optical element to the overall radar system. Previous attempts to convert the information to one figure has often led to confusion and tends to reduce the usefulness of some of the tests. Therefore, in this summary a number of measures of performance will be given so that the reader can deduce whichever values he is interested in.

This section will only summarize the findings, further details of the tests and data will be found in Section 6.0 of this report and in the Processor Final Report.

The performance of the correlators (and of the entire radar system) can be considered in the following categories:

(1) azimuth resolution

(2) range resolution

(3) signal to noise ratio

(4) spurious image content

(5) fidelity of the map

(6) speed of map production

(7) operational difficulty

The azimuth resolution has received the greatest amount of attention, largely because it is the chief reason for using a complex coherent radar system and is the most affected by the problems encountered in the equipment. The range resolution is not unique to the coherent system, and the correlator has adequate resolution to handle the films currently available.

Items 3, 4 and 5 are very complex and few definitive results can be expected until the equipment is performing satisfactorily. The (considerable) effort to date has resulted primarily in system improvements rather than performance data. Items 5 and 7 are not really performance characteristics, but are included in the list primarily because they involve many trade-off items which also affect the other parameters.

3.1 Resolution Criteria

The resolution information can be obtained and interpreted in many ways. The most sophisticated method is to measure the density profile* of the image from a point object (i.e. a perfect hologram in the case of azimuth direction). In ordinary optical systems this is theoretically equivalent to the sine wave response function. A simpler and more common method is to measure the apparent image width or determine the smallest image separation that is just resolvable. These techniques are subject to the observer's judgement and also to exposure and film contrast variations, but when properly done are accurate to 20% or better.

Early in the program it was suspected that there might be a significant difference between the single line width measurement and resolvable pair measurement due to the FM capture phenomenon. Experience has shown that the resolution measurement is little affected by this effect. In this

*Known as the spread function.

report data taken as a line width or minimum resolvable distance has been considered as equivalent.

3.2 Azimuth Resolution

The azimuth resolution is the most important performance factor, and also the most difficult to measure and interpret in terms of the overall radar system performance. Most of the novel aspects of the system bear directly on the azimuth performance, and so most of the problems have been associated with it. A list of the factors which influence azimuth resolution is given in Table 2; it could almost substitute for the table of contents for this report.

The basic optical system gave an image width of 0.0007 inch when tested on the bench correlator with an extremely narrow slit, very small bandwidth, essentially perfect ruled target, and extra optical magnification to reduce the effect of output film resolution. This test was repeated in the Processor and an image separation of 0.0018 inch was clearly resolved with the carbon arc and interference filter. An image separation of 0.0009 inch was resolved visually, and it was estimated that a separation of 0.0007 inch would have been obtained if the experiment could have been pursued further.

A microdensitometer trace was made of a line exposed in February 1963. At that time the resolution was degraded somewhat by a wide (15μ) entrance slit and a target of questionable accuracy. However, the curve (shown in Fig. 23 on page 69) does show the expected shape.

The best resolution obtained while the input and output film were running has been .0028 inch image separation obtained with test target #T150 and the 0.4% bandwidth wedge interference filter.

The finest resolution obtained on F101 flight test film is .0007 inch

Table 2

Factors Affecting Azimuth Resolution

1. Diffraction limit
   (a) radar antenna beam characteristics
   (b) optical aperture, including effects of aperture weighting if any
2. Lack of perfection in optical system
   (a) on-axis aberrations
   (b) off-axis aberrations
   (c) effective field curvature
3. Correlator illumination
   (a) incorrect wavelength
   (b) finite band of wavelengths
   (c) width of input slit
4. Image motion
   (a) incorrect image tracking rate
   (b) vibration
5. Imperfections in input data
   (a) non-linear range sweep rate
   (b) phase and amplitude imperfections in recorded target history
6. Incorrect adjustments
   (a) lack of accurate information about input data
   (b) lack of precision calibration of correlator
   (c) lack of ability to adjust correlator to give optimum image
7. Adjustment trade-off
   (a) speed of processing
   (b) ease of operation
   (c) signal to noise ratio

obtained on the bench correlator from two corner reflectors spaced 4 feet apart.

The best static resolution obtained on the Processor from F101 data is .0014 inch visually (and on the TV) from 10 foot reflectors on S107. Dynamic photographic runs did not quite resolve these targets, the resolution is estimated to be about .0018 inch on one of the runs.

The resolution figures quoted above are for one local area when that area is in optimum focus. This represents the ultimate resolution that can be achieved when studying one area. However, the average resolution across a 9 inch map is much lower because of an azimuth image field curvature. This causes most of the map to be out of focus and to have a tracking error as is explained in Section 7.7. The resolution variation depends upon the focus compromise chosen; for most practical work the resolution varies from .0025 inch a short distance from the center to .003 or .0035 inch at the center and .010 inch near the edges.

The AWAR (Area Weighted Average Resolution) has not been measured for F101 maps. This is partly due to the lack of targets of known characteristic across the entire width of a film, and partly due to the fact that the test program has concentrated on obtaining good maps in the center. The edges of the map have not been ignored, but the steps required to achieve good resolution are too expensive to be warranted for the purposes of the F101 program.

The performance is summarized in Table 3.

3.3 Range Resolution

The range resolution of the Processor depends on the resolution of the

Table 3

Summary of Azimuth Resolution of Correlators

.0007 inch	bench correlator, laser source, approximately 1 square mile field of view. This is the limit of resolution on the best input films.
.0018 inch	best results from Processor. Obtainable over 1 mile range interval for full length of film. Usually requires more than one correlation run.
.0025 inch	resolution obtained on good run over 2 mile range interval.
.0035 inch	average resolution over center 6 inches of map film.
.006 inch	average resolution across entire (9 inch width) map film.

relay lens, effects of the cylinder lens, film tracking, and the film resolution. In the airborne system the resolution is limited by the effective pulse width, receiver bandwidth, chirp compression ratio, CRT and recorder optics resolution, and sweep stability.

The resolution of the relay lens has been measured visually as 65 l/mm on axis and 45 l/mm off axis referred to the output. Measurements in the processor indicate a line width of .0007 inch or less on axis and .0011 inch off axis.

The effects of the cylinder lens are negligible when properly aligned as indicated in Appendix X. Likewise the loss due to poor film tracking can theoretically be reduced to zero and in practice has usually been negligible. The film in current use has an effective line width of about .0005 inch.

Typically, the resolution on the F101 data film has been about .005 or larger (referred to the output). This relatively large width has de-emphasized further study of the correlator range performance.

3.4 Signal to Noise Ratio

At present there is no meaningful data on signal to noise ratio or noise insertion by the correlator. Attempts to measure these quantities have lead to a reduction of stray light but have not given meaningful data. For a qualitative assessment of the signal to noise ratio the reader is referred to Fig. 4.

3.5 Spurious Images

Most sources of spurious images are inherent in the airborne equipment and the data film sensitometry. However, spurious images can be produced by multiple reflection in the optics of the correlator. The only serious source of such images in the Processor has been the interference filter, and this has been mounted in a holder to eliminate these images. On the bench correlator the output film does not move, so all multiple reflection images focused on the image plane are reproduced as spurious images. These usually appear as long lines and thus are not normally confused with real images.

3.6 Speed of Map Production

The speed of map production in the Processor is normally 3 feet per hour. This 3 feet of film contains a map 28 miles long for F101 flight tests.

There has been no attempt to adapt the bench correlator for map production. A one second exposure is required for a 5X enlargement of about one half square mile.

3.7 Map Fidelity

This can be considered in two parts, dimensional accuracy and image fidelity. There has been little interest in the dimensional accuracy on this program and no data is available, but it can be estimated that dimensions are probably correct to within 1% in azimuth. In the range direction there are built in distortions, if rectified the accuracy would probably be better than 1%.

The image fidelity or correspondence between target and image is difficult to define because of the lack of knowledge of how the targets appear. This subject is discussed in Section 7.5, and no attempt will be made to summarize the findings here.

3.8 Operational Difficulty

An unmeasurable but important quality is the difficulty of operating the equipment. In general the interplay of the actual aircraft perturbations and radar performance on the recorded data is not known to the Processor operator. Therefore, for optimum focusing several cut and try runs are required. On the other hand, the Processor is fairly easy to operate to obtain routine maps which are 80% as good as can be optimally attained. The bench correlator can easily vary tilt, focus, exposure, offset or filtering to optimize any particular area, but it is very difficult to make a large area map. At present, the best analysis is obtained by using both correlators.

The specifics of the operational difficulties will not be summarized here, the reader is referred to Section IV of the Processor Final Report, and the instruction manual for details.

Section 4.0

ACCESSORY EQUIPMENT BUILT

4.0 ACCESSORY EQUIPMENT BUILT

A number of auxiliary optical test devices have been built to simulate various aspects of correlation or to perform specific tests. These have all been built on an optical bench foundation to provide for flexibility of use.

4.1 First Optical Bench

The first test unit was a bench fabricated in 1960 to obtain basic data about correlation. A mercury arc lamp was mounted on one end of the bench and its light focused onto a slit. A small aperture collimator of conventional design was used to collimate the light, and a high quality camera lens (180 mm focal length Componon) was used to form the zero order image and correlation images. Black wire was used to stop the zero order light. Some simple cylinder lenses were used to obtain range imaging. A 35 mm camera back with focal plane shutter was used as a film holder. This bench was replaced with the better benches below, but the base and many of the parts are still in use.

4.2 Improved Optical Bench*

The second bench was built in 1962 to support more exacting experiments. This had provision for better alignment, better optics, and capability to insert $9\frac{1}{2}$ inch F101 flight films. A 5 x 7 inch immersion platen was built and used for correlation experiments. Selected areas of the data films were contact

*This unit was also known as the Experimental Processor.

printed and these prints inserted into this platen. The lenses from the Processor could be mounted for testing or to support other experiments. The cylinder lens rider provided precision rotational adjustment around the optical axis.

The bench was used extensively for frequency spectrum analysis, especially in connection with the recorder project. The general appearance of the bench is shown in the Processor Final Report on page 60, more detailed photographs are shown in the November 1962 monthly report.

The optical bench was so useful that a second bench was built for use in the field. The past year's experience has proven the value of having this capability at the operating site as long as the overall system is under development.

4.3 Detail Correlator

A special purpose correlator was built to provide emergency backup for the Processor and provide a special test capability. The original plan was to use a horizontal liquid platen with a bent optical path. Many designs for a vertical liquid platen with leak-proof film slots were studied, but none seemed promising. The advantage of a straight path was finally achieved by making a vertical platen with two large tanks so that the entire reel is submerged. This is cumbersome, but it works and is relatively inexpensive. The straight horizontal path allowed the use of the optical bench for a frame. The same riders as were used on the previous bench were modified slightly to provide for precision tilt adjustments.

This correlator has a 9 inch output image when using white light, so a special camera was made. Various devices have been added to facilitate the experimental work. Photographs of the correlator are shown in Figs. 8 to 14. This unit uses the same optical system as the Processor, these items were the spares for the Processor.

The 110 amp high intensity carbon arc and the condenser system which focuses the arc onto the input slit is shown at the right of Fig. 8. In Fig. 9 the light shield has been removed and the alternate light source, a 1 mw laser is in position. At the left end of the laser a 12 mm focal length lens focuses the beam onto the slit, thus insuring the optical adjustment of the correlator with either light source. A larger laser has been found to be very useful in cutting exposure times it can be inserted with the aid of a mirror. Some of the slit mechanism is just visible to the left of the laser. A shutter (with remote control) is mounted separate from the slit to avoid vibration.

The collimator lens and liquid platen are shown in Fig. 10. The collimator is an f/4 achromatic triplit with a 24 inch focal length. The liquid platen holds the film immersed in tetrachlorethelene between two optical flats. The reels are located in each tank and the film can be positioned in range by raising or lowering the reels. The film can be advanced from the observer's position (at the left in Fig. 8) by the variable speed motor. This film drive is not intended for continuous exposure, but only to bring the image of interest into position.

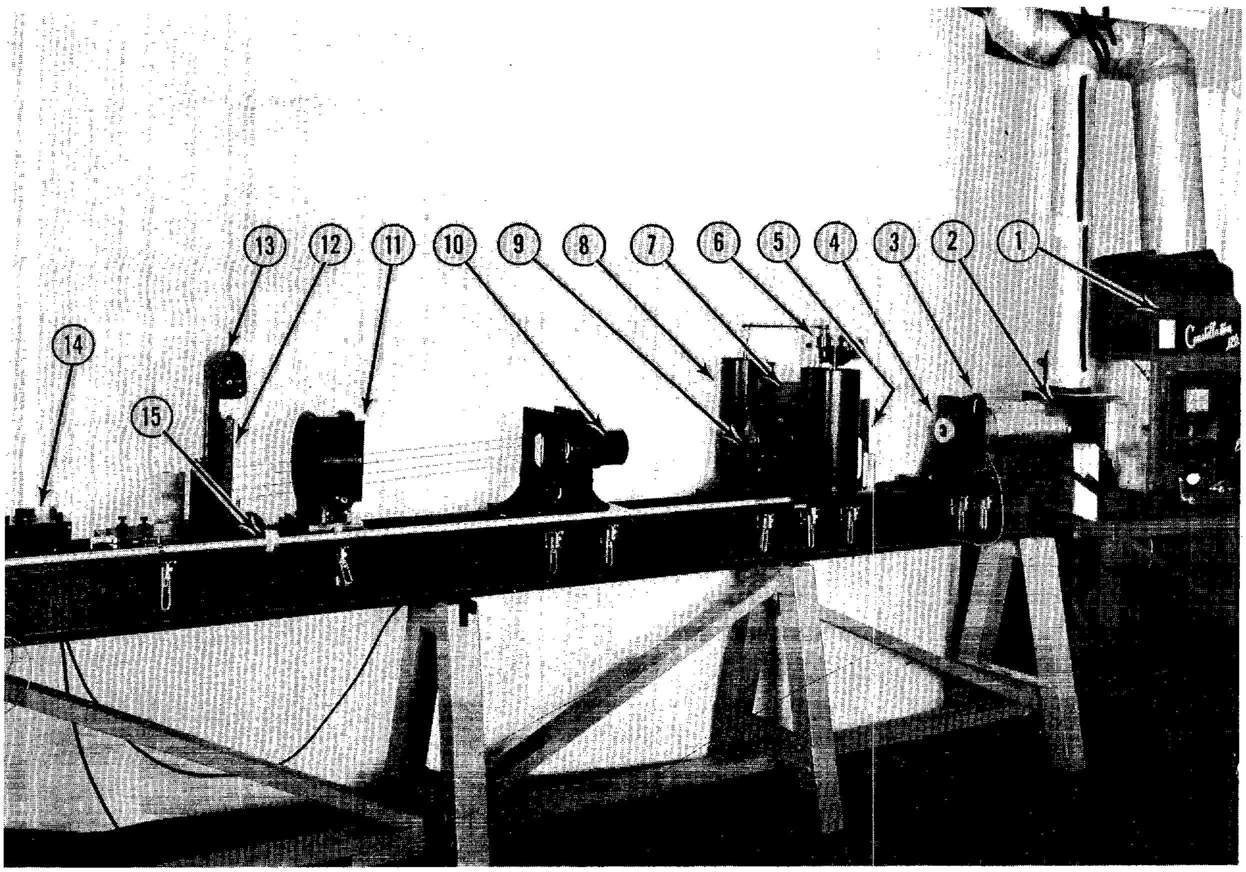
The platen can be aligned perpendicular to the optical axis, and can be rotated around the optical axis to eliminate tilt between the data film and correlator (cylinder lenses and slit). This later adjustment can be made from the operator's position by rotating the tube running along the side of

Figure 8

Overall View of Bench Correlator

The optical system of the Processor is layed out along a straight line. The film in the platen is advanced with the motor controlled by the box at the extreme left. The range is adjusted by lifting the reels (inside the tanks). The tilt is adjusted by a cam on the liquid platen assembly and is controlled by the knob indicated. The zero stop is adjusted with the four cables leading from the camera position. These adjustments are normally made while viewing the output image with a microscope in place of the camera.

1. Light source — 110 amp theater carbon arc
2. Condenser assembly
3. Input slit assembly
4. Shutter
5. Collimator
6. Input film advance mechanism
7. Input film
8. Liquid platen
9. Field lens
10. Relay lens and zero stop
11. Cylinder lenses
12. Interference filter
13. Output film camera
14. Input film advance control
15. Liquid platen tilt control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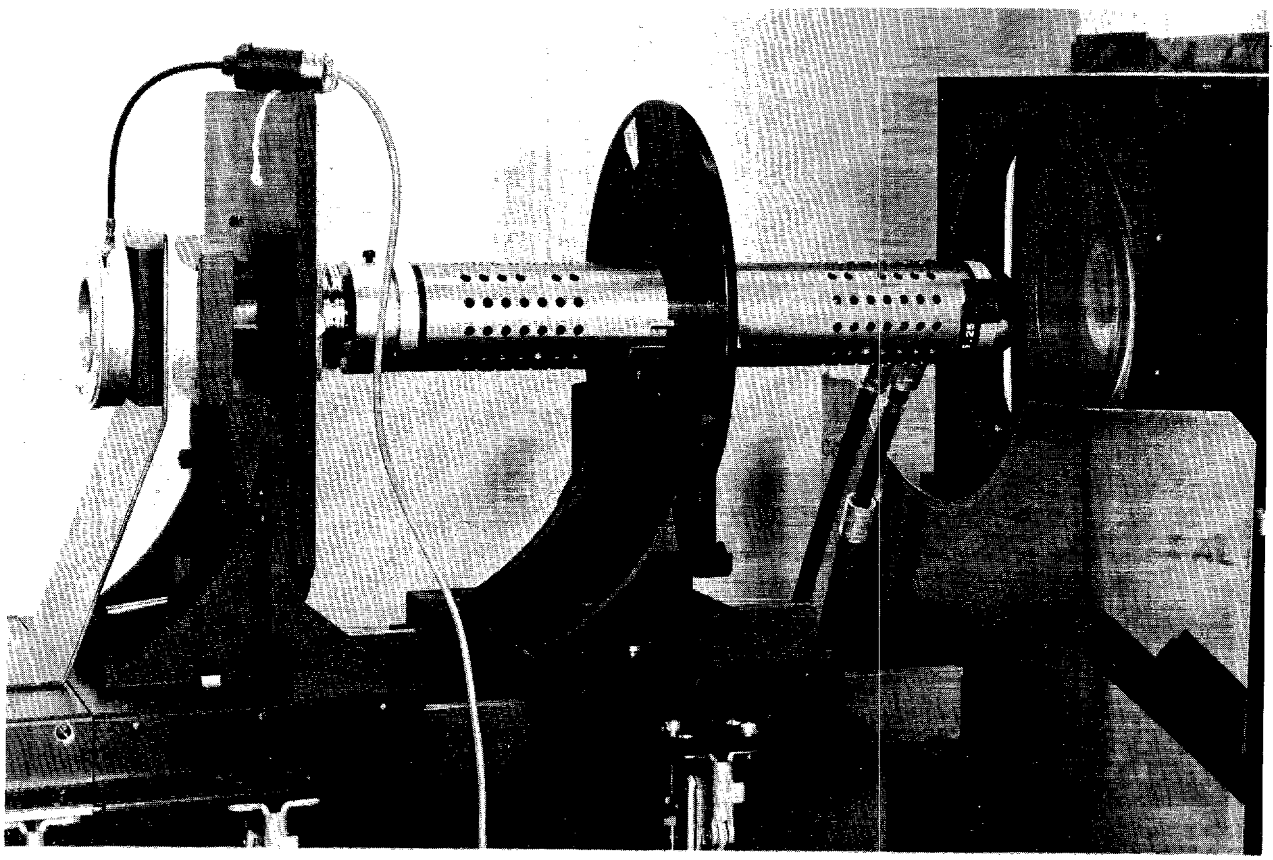

Figure 9

Laser Source on Bench Collimator

The 1 m watt Helium-Neon laser is inserted in place to illuminate the slit. The laser light is focused onto the slit with a 12 mm focal length lens mounted in the collar at the left end of the laser.

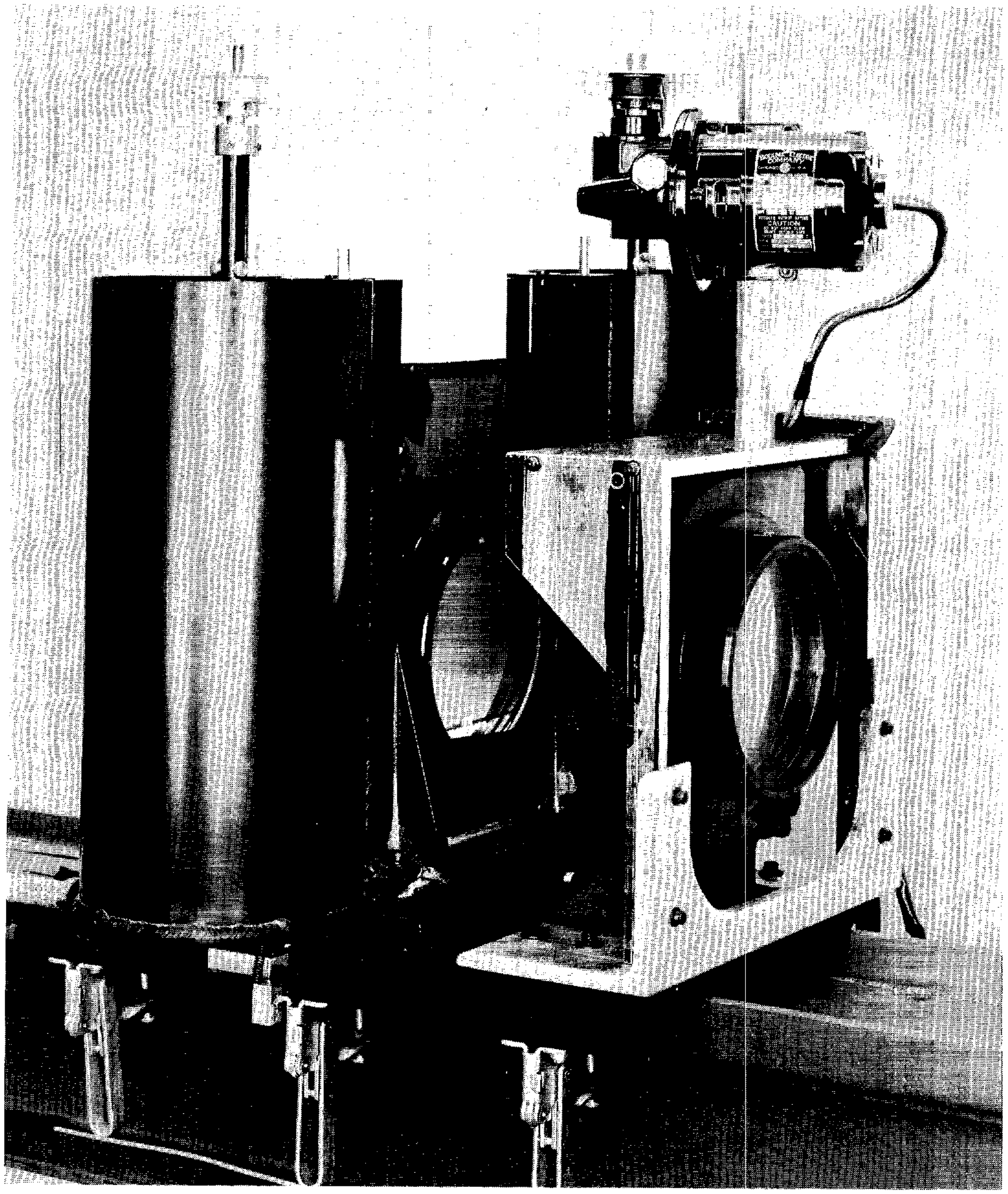

Figure 10

Liquid Platen on Bench Correlator

The film is on $9\frac{1}{2}$ inch reels inside the tank. The film can be seen in and above the tank window. The height (i.e. range) of the film is adjusted with the graduated lift bar at the top. A pully and reversing motor advance the film. The platen can be adjusted in three rotational axies for optical alignment and hologram tilt adjustment. The collimator lens is seen in the foreground.

Figure 11

Details of Rider Assemblies on Bench Correlator

The imaging section of the Bench Correlator as seen from behind the liquid platen. The relay lens and "fixed" cylinder are in the foreground, the large cylinder lens, camera, and film advance control box are in the rear. The features are:

1. Zero stop adjustment micrometers.
2. Zero stop focus adjustment.
3. Lens board tilt adjustment (three per board).
4. Lens board height and tilt adjustment (two per board).
5. Lens board lateral adjustment.
6. Rider guide, 2 cylinders in groove on near side, pad on flat on far side.
7. Rider lock down.
8. Bench alignment adjusting screws, the channel is adjusted against the base H beam below.
9. Cylinder lens rotation adjustment micrometers.

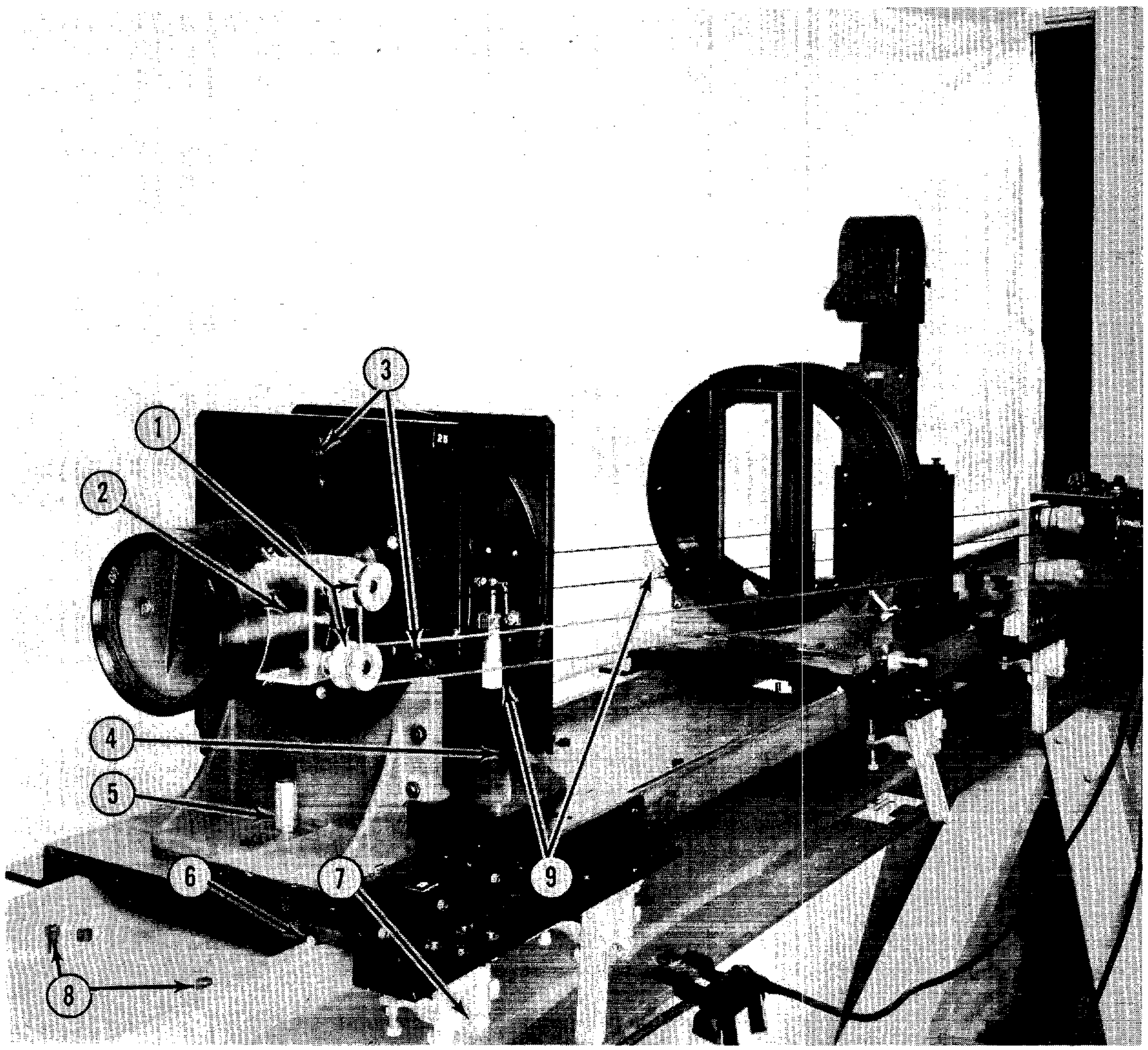
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Figure 13

35 mm Camera

This camera views a full range width of output image. It normally records about 3/4 inch in the azimuth direction.

1. Cylinder lens rotation adjustment.
2. Cylinder lens lateral adjustment.
3. Interference filter in mount.
4. Vertical position of interference filter.
5. Film supply (50 foot capacity).
6. Dark slide in front of film.
7. Film take-up.
8. Camera mount. This mount will also accept a polaroid fixture.
9. Camera advance.
10. Platform for microscope.
11. Post to accept viewing mirror.
12. Liquid platen tilt adjustment.

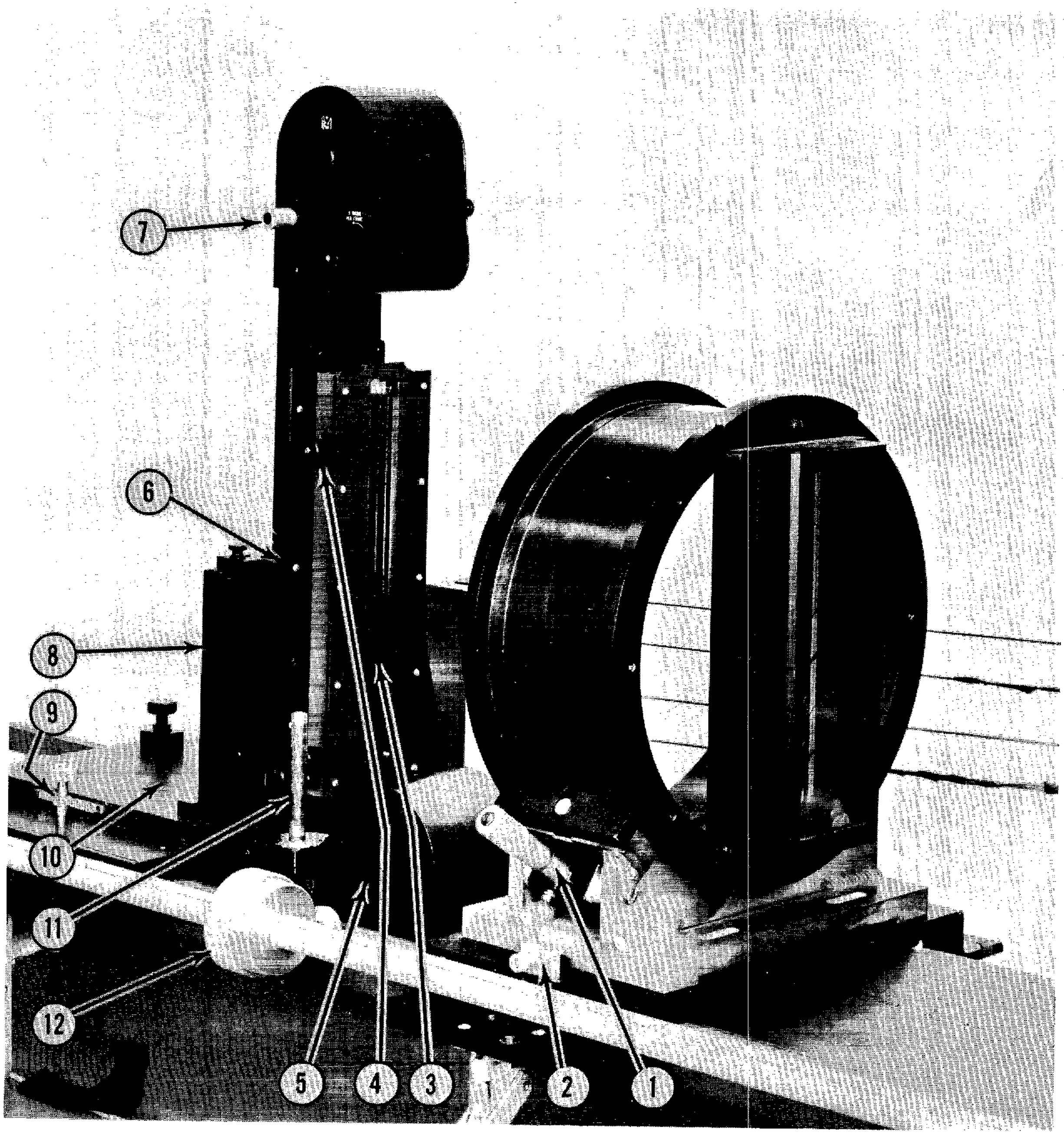
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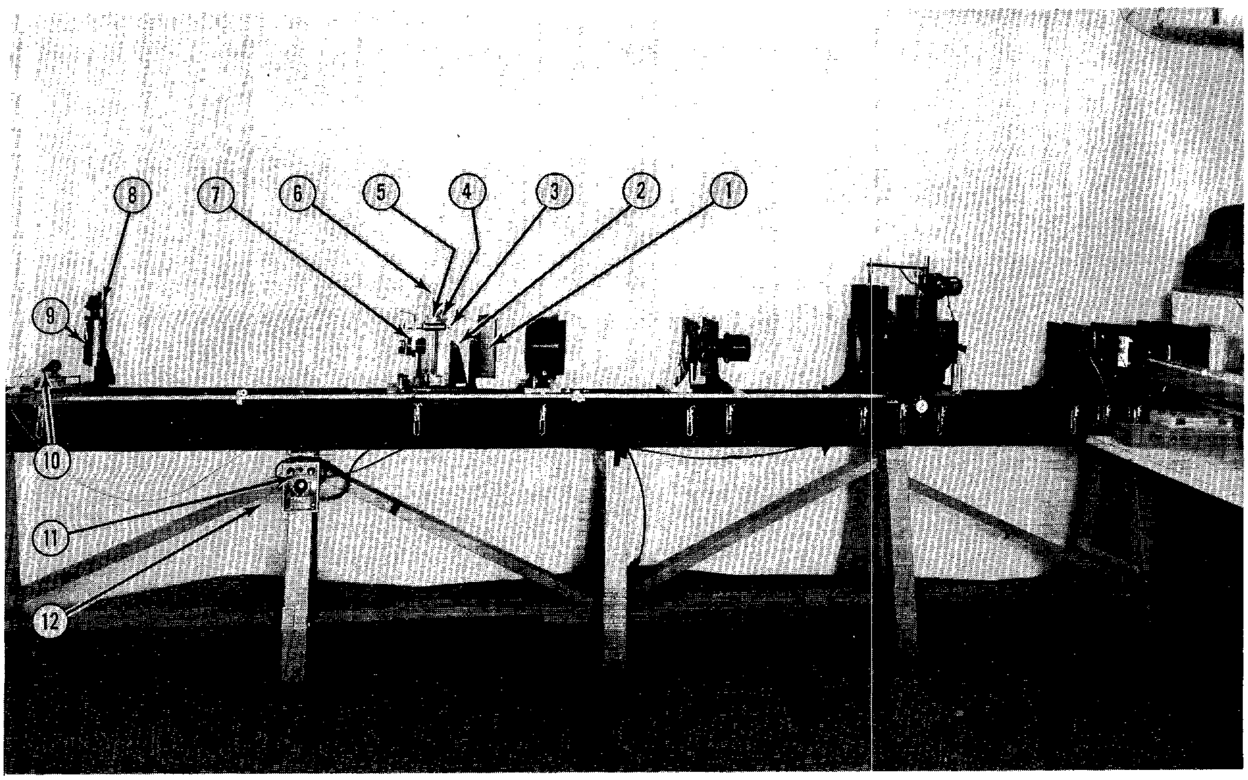
Figure 14

Output Image Viewing Accessories on Bench Correlator

The viewing devices used on the bench. It is shown setup for making 5X enlargements.

1. 45° mirror and viewing screen in position. It can be swung around to photograph the image.
2. Mount for 35 mm camera.
3. Microscope.
4. Lateral adjustment.
5. Focus adjustment.
6. Vertical fine adjustment.
7. 180 mm projection lens mounted so as to have adjustments 4, 5 and 6.
8. 4 x 5 film holder.
9. Polaroid sheet film back.
10. Shutter release.
11. Liquid platen tilt adjustment.
12. Input film advance.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the bench.

The field lens is similar to the collimator lens and can be seen near the platen in Fig. 8.

The relay lens images the range information onto the camera. It is a duplicate of the f/8, 16 inch focal length lens used in the Processor. The zero order stop or spatial frequency cut-off filter is located inside the lens, and is adjusted by the two micrometers shown in Fig. 11. For bench use the remote adjustment has been found very helpful. The relay lens was modified slightly so that the aperture weighting filters could be inserted behind the zero stop as shown in Fig. 12.

Two cylinder lenses are used to refocus the azimuth image. The first is located just behind the relay lens, the rotation adjustment can be seen in Fig. 11. The second lens is mounted further back, and is moved along the bench to achieve azimuth focus. The rotation and cross-slide adjustments can be seen in Fig. 13.

The 35 mm camera is also shown in Fig. 13. The camera has an aperture of 1 x 9 inches. Fifty feet of film is stored in the lower magazine and can be advanced by the crank into the camera and take-up magazine. The camera has a dark slide, but no shutter. For white light operation, the wedge interference filter is inserted in the holder mounted on the front of the camera.

The 35 mm camera can be displaced and the image observed on a ground glass, with a hand magnifier or with the microscope shown in Fig. 14. An alternate assembly will take 4 x 5 plate holders, a Linhoff 70 mm film back or a 4 x 5 polaroid film back. As shown in Fig. 14 the image can also be projected back onto the 4 x 5 film holder with a projection lens. The lens is usually tilted to match the range focus variation of the holograms on the input film.

This unit has been used continuously for the past year, and most correlations in this report that are not from the Processor were made on it. In addi-
STAT tion [redacted] Westinghouse personnel have used it from time to time. A similar unit, using available lenses, has been built for Westinghouse in 1965.

Section 5.0

DATA SIMULATION

5.0 DATA SIMULATION

The Processor normally uses data from a coherent side-looking radar system as an integral part of its optical system. Very little meaningful work can be done on the Processor without that data or simulated data. For this reason, the first step was to generate a pattern which would simulate that data. This section describes the simulated patterns made on the project.

5.1 Requirements

The data produced by the radar is an overlayed complex of dots on a photographic film as is shown in Fig. 3. Each point in the scene gives rise to an exposed line lying along the azimuth direction. This line varies in transmission along its length in a specific fashion as determined by the physics of the radar situation*, such that

$$\sqrt{T} = T_o + A \sin kx^2$$

where T is the film transmission, T_o is a nominal transmission, A is related to the modulation, x is distance along the film, and k is a constant for one pattern dependent on the parameters in the radar system. This variation is commonly characterized by electronic engineers as a linear

FM (frequency modulation) signal, and it is described by optical engineers as a slice of a zone plate. The data film obtained by flying past an ordinary complex scene is a composite of many such individual patterns.

5.2 Pattern Types and Techniques

A number of patterns and pattern arrays can be simulated. Single patterns can be drafted or ruled on machines to generate "square wave" patterns, i.e. those having only two transmission levels. These can be photographically reproduced to obtain any scale factor or "focal length" desired by changing the effective value of k. They could also be reproduced in a limited resolution system or a system using spatial filters in the diffraction plane to produce approximate sine wave transmission. Single patterns could be generated by recording suitable interference patterns (such as Newton's Rings). The pattern could also be generated by moving film past a narrow light source which changes in intensity in a controlled fashion (the method actually used in the recorder sub-system of the radar unit).

A single pattern can also be simulated in a different sense by using a cylinder lens at the position of the data film.

Multiple patterns for specific purposes can be made by multiple printing single patterns onto a single photographic film. This technique has certain limitations, particularly the fact that the incoherent summation of exposures in overlapped patterns instead of adding radar phases gives rise to distortions in the array.

Multiple patterns could also be generated by adding phases in an interferometer system, or computing complex signals to modulate a light source in the moving film technique. These techniques could also be utilized to make an array simulating a continuous tone scene.

Most of the techniques mentioned have been investigated. The single square wave target has been made and is discussed in the following section. Some patterns were obtained using interference techniques during a study phase in 1960, but the capability of the system was limited and it was not pursued at the time. Later interest in interference techniques centered about continuous tone array simulation. A number of techniques are feasible, but difficult (and therefore, expensive) and were not formally proposed or pursued on this project, partly because it was anticipated that F101 flight test film would fulfill the need for such pattern arrays. However, this technique was pursued on an in-house project as is described at the end of this section.

The techniques of modulating a light source and moving film was investigated and proposed. A fast digital computer was to be used to modulate a cathode ray tube in one of the recorders built for the radar system. This technique has the disadvantage that the limitations of certain computer functions would preclude generating a continuous tone array, and the technique would inherently include the recorder and its problems in the resultant data. After further considerations, this technique was dropped from the proposal. However, later testing on the recorder program has resulted in swept FM patterns being generated for some test purposes, and these patterns have been used for some tests.

Some of the work has raised questions which could best be investigated with a cylinder lens pattern simulation. Such a lens was fabricated and used, but it was not feasible to test it adequately to justify its use as a test device.

5.3 Ruled Pattern Manufacture

All of the simulated targets which have been used to test the Processor have been made by using a ruled pattern. This was accomplished by first making some test rulings and photographing them to establish optimum parameters for the master. One of these test rulings was used to make the 24 inch focal length patterns used for the 1961 acceptance test. The next step was to program the formulation of a pattern on a Royal-MacBee computer to print out the 3000 necessary settings without error. The data results from the equation

$$x = \sqrt{\frac{n}{10}} \pm .0018$$

where + is used if n is even, - if n is odd. n is a running integer, x is the coordinatograph setting, and .0018 is the effective half width of the scribing diamond.

The ruling was done on the Haag-Streit coordinatograph, a precision measuring and ruling device shown in Fig. 15. The master was then contact printed to give film sub-masters. These were reduced photographically in precision reticle cameras to the scale factor desired. An array of sub-masters and the resulting scaled masters are shown in Fig. 16. These scaled masters were then contact printed to give the patterns and pattern arrays used in the Processor.

The first patterns used were on small pieces of film which were convenient for static tests. Later the master was mounted in a precision repeating printer known as a Misomax, and pattern arrays with accurately controlled overlaps and locations were made on $9\frac{1}{2}$ inch wide film. As the capability of

Figure 15

Ruling the Master Zone Plate

The master zone plate is shown on the table of the Haag-Streit Coordinatograph. The ruling diamond is in position on the master. The individual settings were accurate to .0003 inch.

Figure 16

Zone Plate Sub-masters

The master was contact printed onto high resolution film. These sub-masters were then reduced to the size shown above.

the Processor and Bench Correlator improved, better targets were needed and were made.

The phase accuracy of the targets has been a prime goal. The master was ruled to an accuracy of better than .001 inch at each point over its 20 inch length. Glass was used as a substrate to preserve this accuracy. In the sub-masters overall shrinkage only alters the scale factor and differential shrinkage is less than .001 inch. The optical reduction process must be carefully implemented if harmful distortions are to be avoided, so reduction was done on a precision camera with a low distortion lens. The reduced pattern was checked on a Mann Comparitor and found to be quite good. The latest series of targets were accurate to better than $\frac{1}{4}$ cycle of the highest frequency. These were used to make the precision targets T150 and T160.

The test films which have been made are listed in Table 4 and Table 5. Table 6 describes T115 in further detail. Some photographs showing some examples of these patterns are shown in Figs. 17, 18 and 19. Overlapped arrays consisting of 2 and 5 patterns have been made with a wide range of separation. An attempt was made to overlap 30 patterns, but the sensitometric problems of dealing with many very weak exposures prevented any useful results. Some patterns were printed on grainy film to simulate noise.

5.4 Continuous Tone Data Simulation

The continuous tone data that has been used has come from the F101 Flight Test program. None of this data is perfect, nor is any of it accurately defined as to frequency content, linearity, modulation, or a host of other factors. However, it has been very helpful in working with the Processor. No attempt will be made to describe it separately here, and the reader is

Table 4

Single Targets Suitable for Static Testing

T-1*	Standard Air Force resolution target good to 6-6 group
T-2	24 inch** overlapped
T-3	24 inch for 3 colors
T-4*	Gurly long-lines range test target
T-5	150 inch and 200 inch singles
T-6*	Aerial Photo Boston
T-7	24 inch
T-8	24 inch three colors positioned on $9\frac{1}{2}$ inch film
T-9	200 inch .001 wide
T-10	150 inch .001 wide single
T-11	140 inch .001 wide various densities
T-12	150 inch two inch wide paste up area
T-20*	Long line 66, 88, 110 l/mm
T-21*	Long line 40 l/mm
T-22*	Long line 32 l/mm
T-23*	Long line 24 l/mm
T-24*	Long line 72, 96, 120 l/mm
.....	Various 150 inch and 200 inch targets

* Indicates test films which are not "patterns."

**The figures refer to the focal length of the pattern in green (λ = 550 or 546.1) light.

Table 5

Targets Exposed on Long Lengths of $9\frac{1}{2}$ Inch Wide Film

T101*	scribed every 3 feet
T102*	grid and resolution for clocks positive
T103*	grid and resolution for clocks negative
T104	200 inch non squint .001 inch wide
T105	200 inch squint .001 wide overlapped
T106	200 inch non squint overlapped
T107	150 inch squint .001 inch wide various densities
T108	150 inch squint .001 inch wide overlap
T109	200 inch dot low
T110	200 inch dot medium
T111	200 inch dot double overlap high density .010 to .001
T112	200 inch dot double overlap very high density .101 to .001 sep.
T113	200 inch dot 5 overlap low density .060, .045, .030, .015, .000
T114	200 inch dot 5 overlap high density .060, .045, .030, .015, .000
T115	150 inch squinted double and 5 overlap high, medium, and low density
T116	150 inch squinted noisy double and 5 overlap high, medium, and low density
T117	200 inch non squint as T115
T118	200 inch squint as T115
T119	150 inch non squint as T115
T120	150 inch squint 71 patterns evenly spaced
T150	150 inch squinted pairs, high, medium and low density
T151	200 inch squinted pairs, high, medium and low density
T152	150 inch squinted pairs, high low and low high overlapped
T153	200 inch squinted pairs, high low and low high overlapped
T154	near range, 3 color overlapped
T155	far range, 3 color overlapped
T156	150 inch squinted and overlapped, 016 separation
T157	140 inch squinted pairs, .001 wide as T150
T158	200 inch squinted pairs, .001 wide as T150

T200 series. Copies of any of the T100 series.

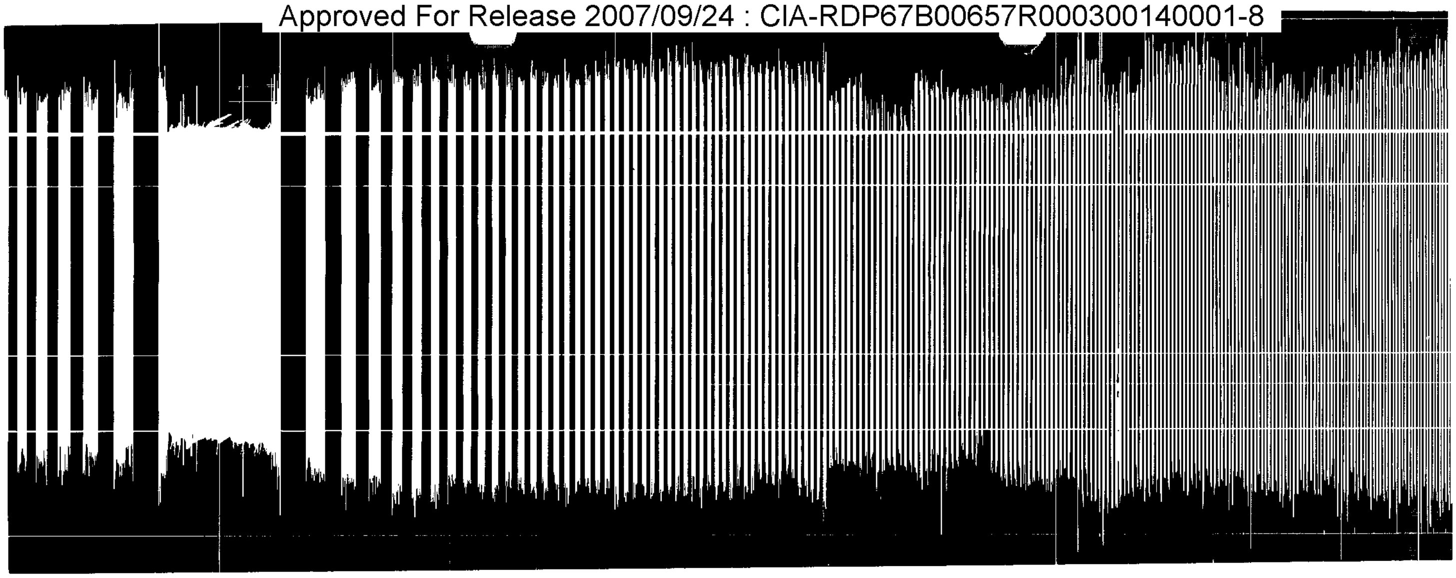
*Indicates test films which are not "patterns."

Table 6

Parameters of Test Pattern T115

Test Film T115	Patterns Per Set	Sets Per Series	Density	Pattern Separation (inches)
Series I	2	12	both high	.000, .040, .036, .028, .024, .016, .012, .008, .004, .000*
Series II	2	12	both medium	same as series I
Series III	2	12	both low	same as series I
Series IV	5	5	all high	.060, .045, .030, .015, .000
Series V	5	5	all low	same as series IV
Series VI	2	12	high-low	same as series I
Series VII	2	12	low-high	same as series I

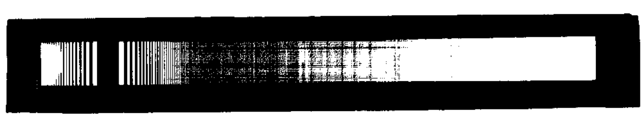
*Single pattern for line width test.



a. portion of the master

b. 200 inch focal length squinted

c. 150 inch focal length squinted



d. 150 inch focal length entire pattern

e. [illegible] inch focal length

Figure 17

<u>Full Scale Prints of Zone Plates</u>

The lines along the length of the pattern were scribed so as to be perpendicular to the main rulings. The two central lines are reproduced on all patterns for tilt and range checks.

Figure 18

Overlapped Zone Plates

Each of these are made by double printing a sub-master with a shift between printing. The shift is approximately .002" (top), .010" (center), and .080" (lower). Note the Morie banding.

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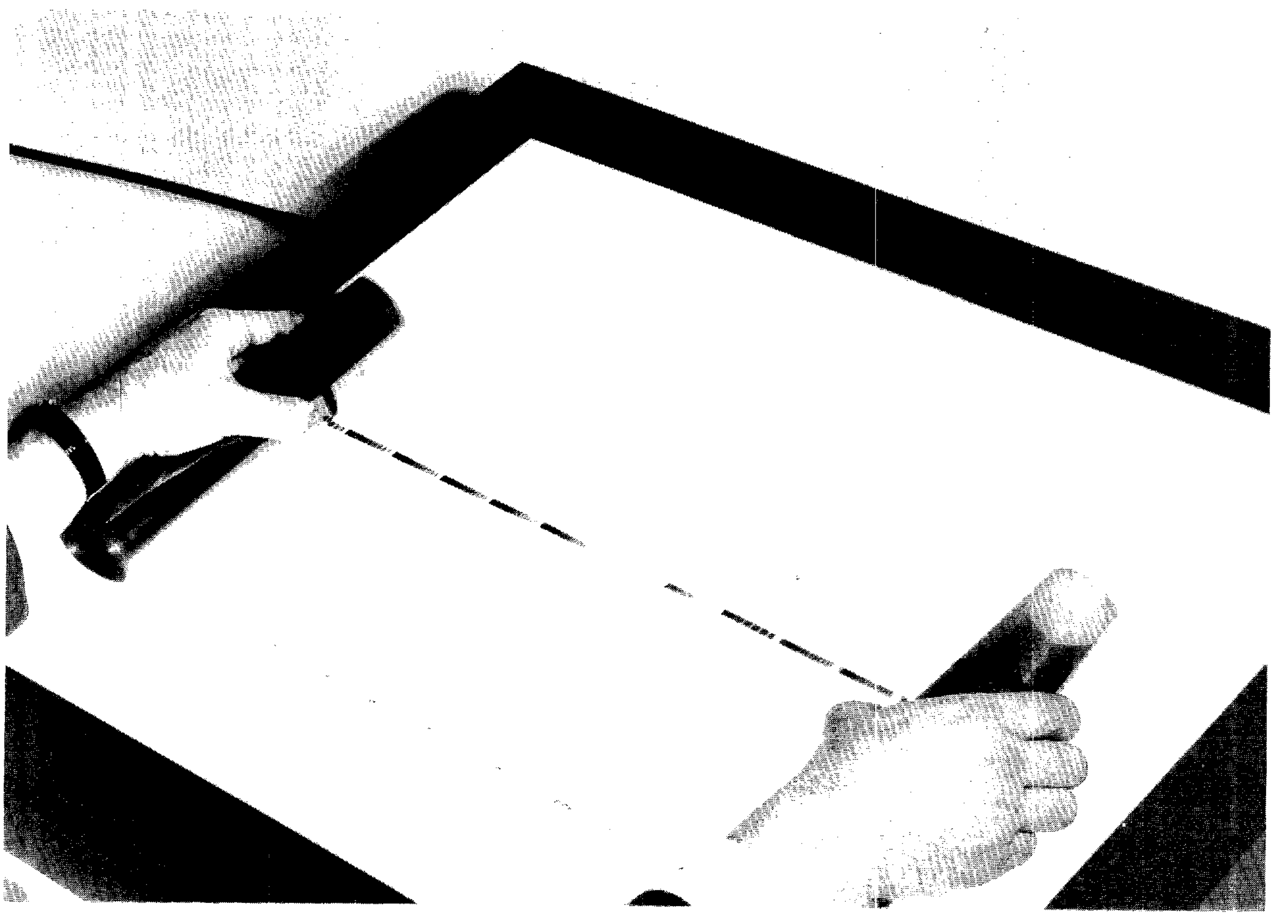

Figure 19

Test Film

The targets are printed in precise registration on a roll of $9\frac{1}{2}$ inch film for use in the Processor. A section of test film T115 is shown.

referred to Section 8.3 where the overall flight program results are discussed.

Throughout the program the possibility of making continuous tone simulated data was considered. A number of techniques were studied; but each required expensive equipment and considerable project time to obtain usable results. Early in 1963 a new light source, the helium-neon laser, became a practical tool and reduced considerably the effort required for most interference experiments. At that time Itek sponsored an in-house project to make holograms and generate synthetic data suitable for the 9015 Processor. The research report is contained in Appendix VIII.

To simulate radar data for this system a hologram with the following special characteristics is required:

(1) Dispersion is required only in the azimuth dimension, with normal imaging in the range dimension. (This is not the case with a chirp system, but even here the dispersion is different in the two dimensions, requiring an astigmatic system.)

(2) The offset or squint angle and the hologram spatial frequency bandwidth must be constant.

(3) A large azimuth stretch-out of about 8:1 must be provided.

(4) The hologram focal length is very long, approximately 150 inches.

None of these requirements are met with the conventional method of hologram generation so a specially designed astigmatic optical system, described in some detail in Appendix VIII, was constructed.

These holograms were of constant focal length and therefore would have been in focus at only one range interval in the optical processor.

The optical generation of holograms with variable focal length across the range dimension is a more difficult problem. With the constraint that input and output film planes be flat, it is found that the focal length resulting from tilting input and output planes is not a linear function of distance off axis, but contains quadratic and cubic terms. By suitable design, these terms can be held to a negligible value, but it was found that the azimuth: range stretch-out ratio could not simultaneously be held at the required value. These problems could have been solved or circumvented with additional project effort. The combination of F101 films and test targets were good enough so that the additional work was not warranted.

Section 6.0

TEST PROGRAM

6.0 TEST PROGRAM

The Processor and bench correlator have been in use continuously since they were built. Most of the work has contributed to a better understanding of the Processor, the correlation process, and the coherent radar system. A Processor test program was initiated in 1962. The testing has continued throughout the program and is intertwined with the modifications, F101 data processing, and studies performed. The specific test directed toward Processor performance is discussed in this section. All of the topics originally proposed in the Test and Simulation program are discussed.

6.1 Resolution in Range

In the range dimension the Processor is similar to an ordinary 2X enlarger except for some details which should only have a secondary effect on the resolution. For this reason an "ordinary" resolution target of lines and spaces is adequate. This is placed in the platen with the lines running in the azimuth direction, and the resulting image observed or photographed at the output image plane.

The optical system of the Processor must be modified by removing or misaligning the zero order stop since there is no azimuth detail to diffract any light past that stop. This should not have any effect on the applicability of the test data, and some of the tests verify this assumption qualitatively.

The correlator optical system is illuminated in a very special fashion, with highly collimated light in azimuth. This leads to diffraction effects which tend to make the images complex and interpretation difficult. An attempt to eliminate this problem and to measure range resolution by illuminating the platen with incoherent light gave very low resolution readings (only a few lines per mm). Much of this loss was traced to the spatially incoherent illumination. The 4 element relay lens was designed with ray trace data from rays that will actually exist in the Processor. As a result the aberrations are not controlled for all possible rays passing through any part of the aperture. Tests on a lens bench, without the cylinder lenses, indicated that a diffusely illuminated target gave very low resolution, but that good resolution was attained when the optical path was baffled to limit the rays to those anticipated in the Processor. A resolution of 65* l/mm on axis and 45 l/mm at the edge of the field was obtained using a standard 3 line Air Force Resolution Test Chart. The addition of flat glass to simulate the platen and cylinder lens glass thickness made no noticeable changes in the image.

The lens bench tests were repeated in the Processor with the aid of this new knowledge. Visual results of 60 l/mm on axis and 40 l/mm off axis were noted, but the data is questionable since the effects of diffraction and spurious out of focus images could not be avoided or evaluated. Photographic tests were experimentally difficult, and did not achieve resolution of better than 20 l/mm.

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*All resolutions are referred to the output or map film.

In February of 1963, the long line range resolution tests were rerun with the better cylinder lenses. At this time, it was realized that the limited aperture, especially when the zero order slit was in place, prevented the diffracted energy from high frequency targets from getting to the image. The tests were changed from measurements of the smallest resolvable line spacing to a measure of the contrast at a nominal line spacing. An enlargement of the results of a photographic test at 20 l/mm is shown in Fig. 20. The contrast on the originals was 58% on axis and 35% off axis. This would indicate a half power width of .0007" on axis and .0011" off axis.

A second method used to check range resolution was to observe the image formed by a line .002 inch wide scribed along each edge of the patterns (see Fig. 17). When this image is correlated this line should leave a .004 inch gap in the resulting image. (For example, see Fig. 22 below.) This has not been accurately assessed quantitatively, but it has maintained a check on the range performance and has the advantage that it is obtained while the system is working in its correct alignment.

Another check on range resolution is obtained by processing a pattern which is approximately .001 inch wide and should give an image about .002 inch wide in range. Attempts to obtain good point images with the old cylinder lenses led to poor results in azimuth, but range image width of about .003 inch were obtained as shown in Fig. 21. This technique was experimentally difficult, and has not been pursued further.

The range resolution has also been measured by inserting a film with a set of very narrow (.0002") clear lines running the length of the film.

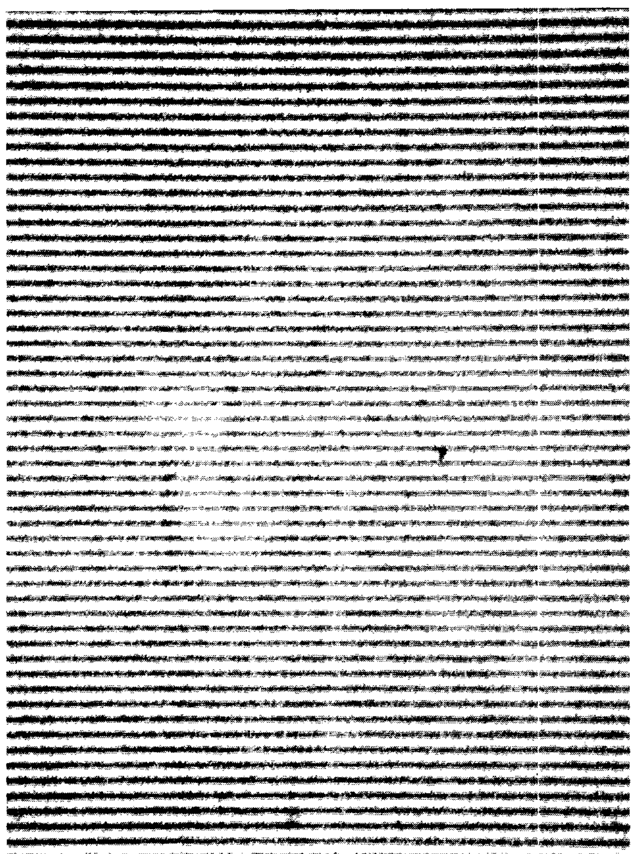


Figure 20

Range Resolution Test Image

This is an enlargement (40X) of a photographic image made to test range resolution. A long line square wave target was placed in the input platen of the Processor and this image was recorded at the output. The original photograph was measured on a microdensitometer to determine the contrast.

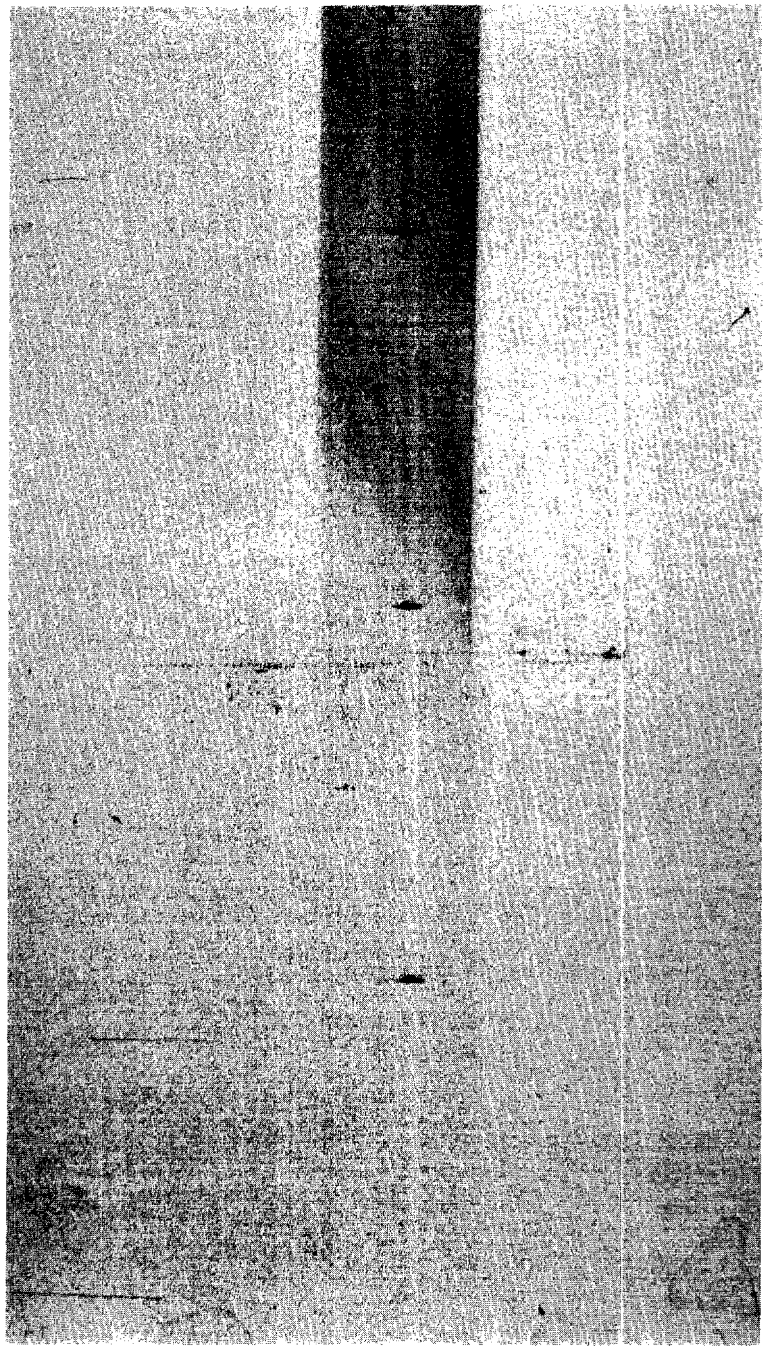


Figure 21

Dot Images

This is an enlargement (approximately 10X) of a number of dot images. The input zone plate pattern was approximately .001 inch wide and it should ideally correlate to a short line .002 inch long in the range direction. In this photograph the azimuth (horizontal) length is relatively long, but the range spread is .003 inch or less, indicating good range resolution. The dots shown vary in exposure.

These would form a set of geometrically ideal lines .0004" wide on the output. The image was recorded on Royal-X Recording film and the test was run with the films driving at normal speed. The measurement gave line width of .0012" on axis. The lines near the edge of the field were not measured, but they appeared to be only slightly wider.

6.2 Image Size in Azimuth

The width measurements have been made on line images formed by patterns shown in Fig. 17. The first correlated images obtained in November 1961 were observed visually and judged to be diffraction limited (the pattern was relatively short). The images were not photographed, so that data could not be analized and carefully interpreted. Data obtained in May 1962 gave line widths of .005 inch to .006 inch in many runs, both static and dynamic. Further tests and observations made during the flight test support work continued to give about the same performance.

In November 1962, the new cylinder lenses were installed and the line width tests were resumed. Some preliminary line widths of .003 inch width were obtained under idealized conditions (the aperture of the pattern was reduced to give optimum results). The best data obtained during that period was that obtained in February 1963. This gave a line width of .002 inch with a medium width (15μ) slit and a 0.4% bandwidth interference filter. An enlargement of the image and a microphotometer trace of one line is shown in Figs. 22 and 23. Attempts to narrow the line below a .002 inch width lead to a critical examination of the test target. The target was found to have some phase error, and new targets were made. By 1963 it had been established that image separation was a dependable method of measuring test

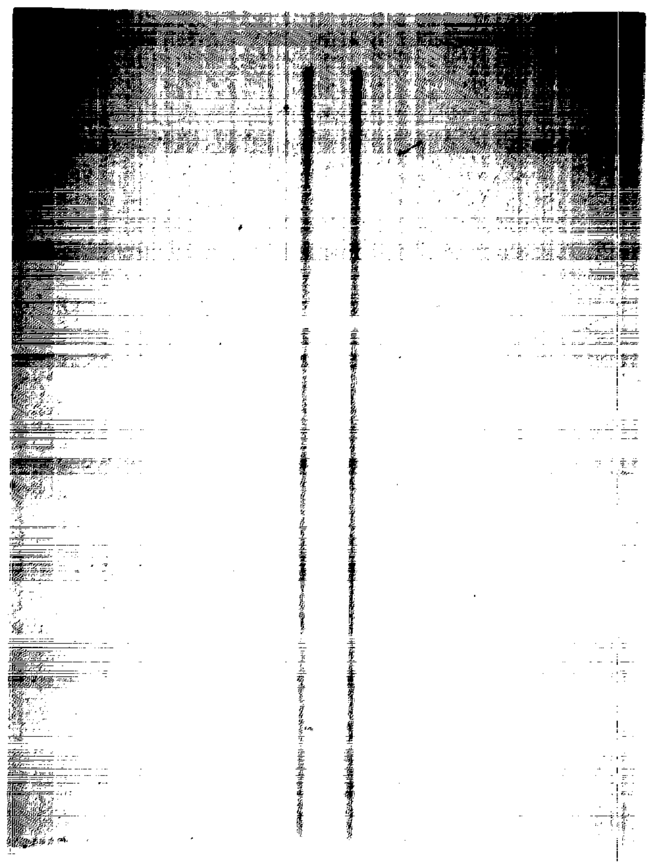


Figure 22

Azimuth Line Image

This is an enlargement (35X) of an image formed by two overlapped patterns as shown in Fig. 18. The two lines are separated by .007 inch in azimuth. The breaks in the lines are the range check lines. They appear tilted, this would indicate that the pattern and cylinder lenses were misaligned by a few minutes of arc. (This would have almost no effect on azimuth line width.)

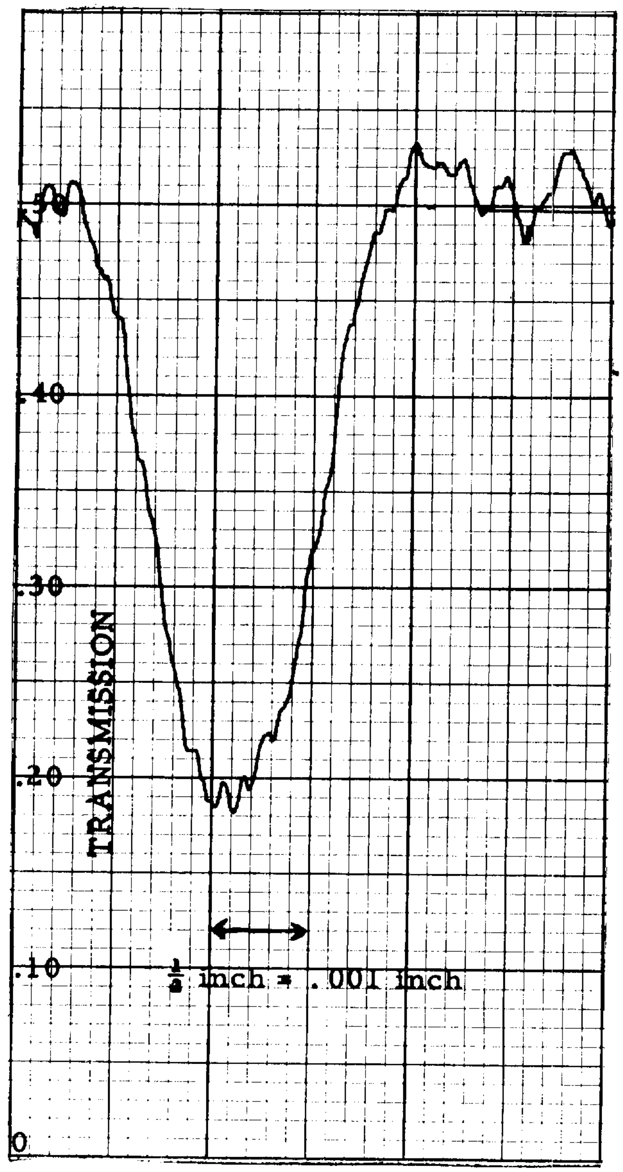


Figure 23

Microphotometer Trace of Fig. 22

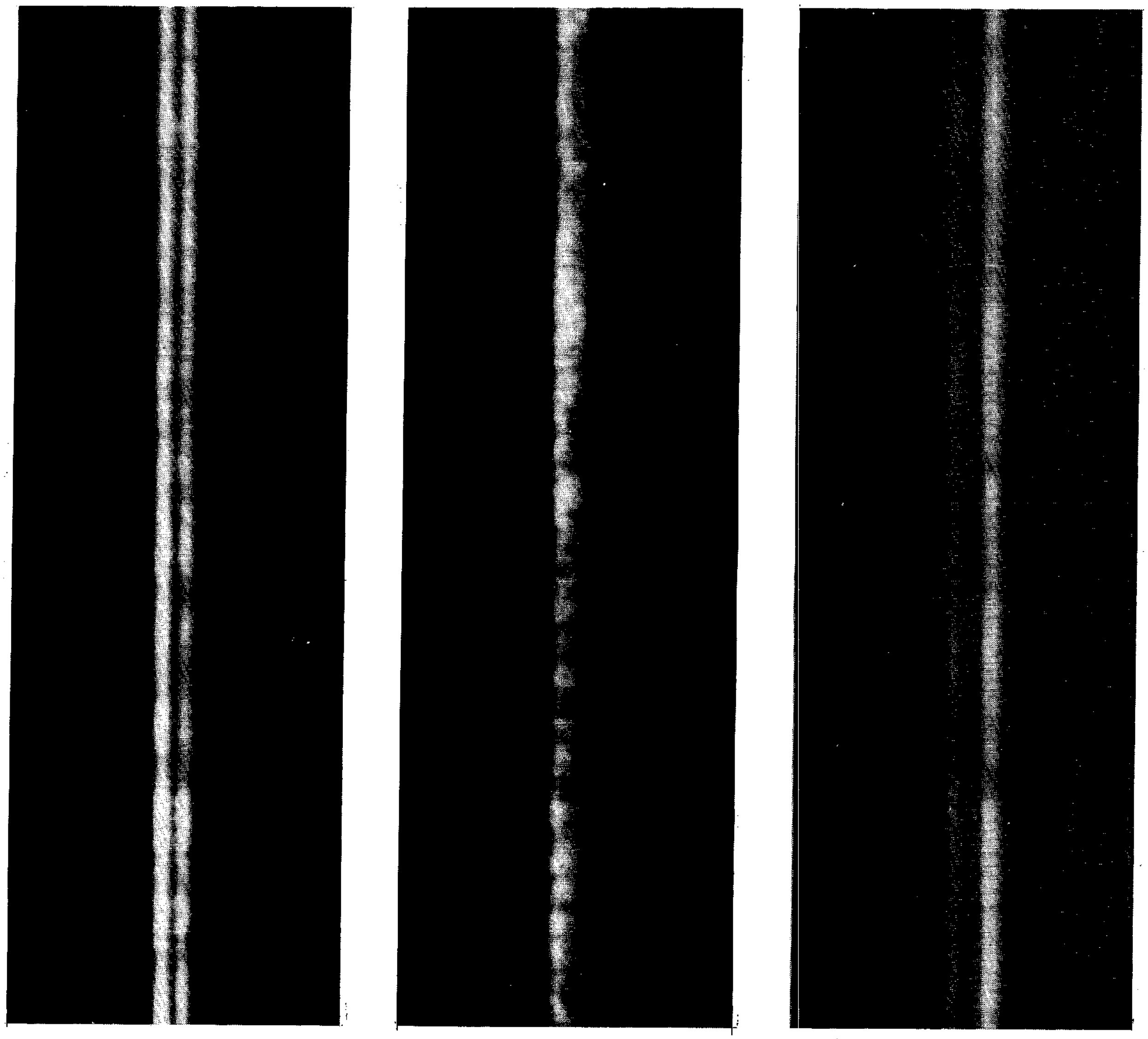
This is a transmission trace of one of the lines shown in Fig. 22. The trace was made with a microphotometer on the original negative.

target resolution, and the later tests used this simpler technique as discussed below.

6.3 Azimuth Signal Separation

The separation of images of two simulated targets which are close together in azimuth was first tested in February 1962. Most of the patterns used are double exposures of a single square wave test target as described in Section 5.3 and shown in Fig. 18. Images separated by .0045 inch on the output film were resolved with the 24 inch focal length system before the Processor was converted to a 150" system. In November 1962, as soon as the good 150" optics were installed, a separation of .0027 inch was photographed and resolved. In February 1964, a laser was jury-rigged into the main correlator between the input slit and the main condenser assembly. The test pattern used on the bench was used here and again images separated by 0.0009" were well resolved visually and photographically, see Fig. 24(a). New test targets were made with closer spacing and it was observed that the azimuth resolution limit was between 0.0007" and 0.0009". A separation of 0.0008 inch represents approximately 4 feet separation of targets in azimuth on the ground from flight test altitude.

Aside from bandwidth, there was no apparent reason why the correlator could not do nearly as well with the carbon arc and the wedge filter so resolution tests under these conditions were pursued again. This time it was possible to obtain, with the original targets, 0.0009" image separation visually, and 0.0018" separation photographically, see Fig. 24(c). The targets separated by 0.0009" in image space could not be resolved photographically due to an effect that at first appeared to be vibration from the



.0009 inch separation laser

(a)

.0007 inch separation laser

(b)

.0018 inch separation carbon arc

(c)

Figure 24

Azimuth Line Separation

These are three enlargements (100X) of tests made with overlapped targets in the Processor.

carbon arc. In subsequent tests with the laser it was discovered that air turbulence in the region between the upper input platen and the input slit was the source of the difficulty. The air turbulence was created by the cabinet exhaust fan and was eliminated by inserting the light and dust baffle around the upper platen. Resolution tests were not completed with the carbon arc after this discovery because of necessity of preparing the correlator for shipment. If was felt, however, that target separation of less than 0.0009" in the image plane could be photographed using the carbon arc and wedge filter once the problem has been identified and corrected.

Some tests were run with 5 overlapped patterns. The sensitometry of the pattern making process becomes much more complex. Film inertia, reciprocity law failure, pre-exposure, and post-exposure effects combine to cast considerable doubt as to the exact nature of the resulting pattern array. The pattern does create five images although not as good a separation nor with equal image intensities.

6.4 Focal Length Compensation

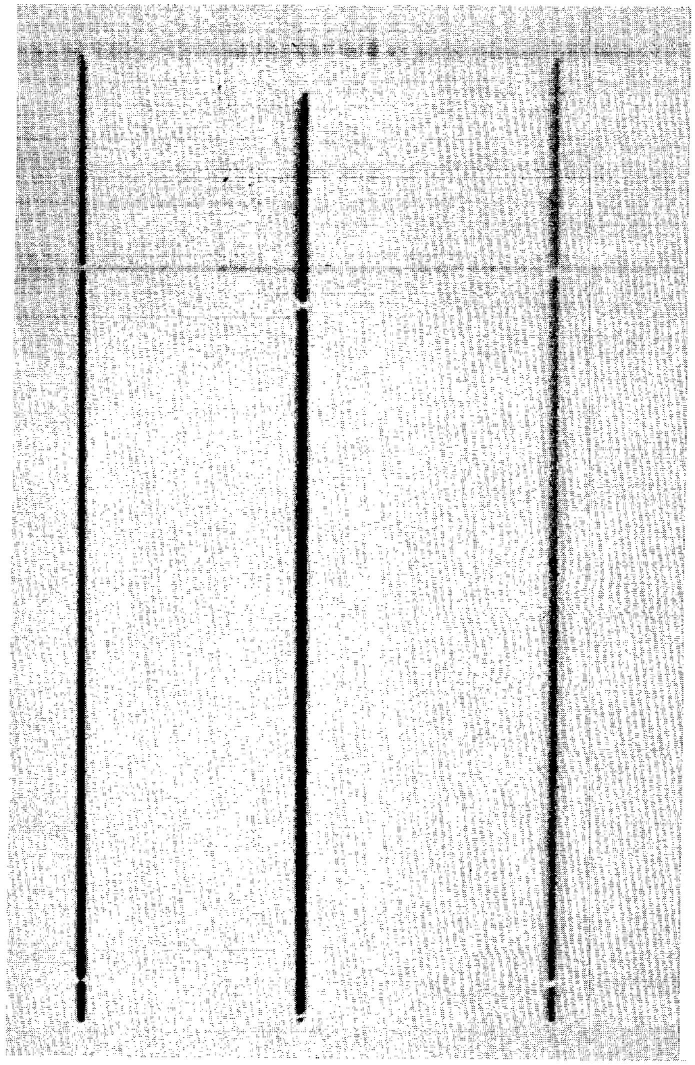
This test was intended to demonstrate that the wedge interference filter technique would compensate for the variation of pattern focal length with range. The test was envisioned before the Processor had correlated any data film and was designed to (a) prove and demonstrate that wavelength compensation works, and (b) uncover any unsuspected problems associated with wavelength compensation. A series of three targets were made for the 24 inch focal length system and checked visually in December 1961. This test showed qualitatively that the focal length variation was corrected, but the results were not quantitatively conclusive and photographic records were not obtained.

In February 1962, some slightly different tests were recorded which demonstrated that the image does go through focus when the wavelength is changed. The results are shown in Fig. 25. At that time the quantitative interpretation of the data was poor due to the cylinder lens problem. By the time good cylinder lenses were installed the wavelength compensation had been adequately demonstrated with F101 film and this experiment was not pressed further.

6.5 Pattern Tilt

This test was intended to verify the theoretical finding that the azimuth line width and range resolution would be sensitive to tilt angle misalignments on one minute of arc. It was expected that this sensitivity would not be experienced until the Processor was performing to its full optical capability.

Experience on the Processor verified these expectations. It was found that angular rotations could usually be readjusted to within 3 to 5 minutes of arc by observing the two range resolution marks on the line images (see Fig. 22). A visual test run in April 1962 to determine the effect on line width gave a noticeable spreading with a 5 minute misalignment. The tests using dot patterns described in the range resolution section above required that the alignment be within 10 or 15 minutes of arc before the image could be even found in the image plane. Recent experience has indicated that the better resolution obtained with the good cylinder lenses does demonstrate increased sensitivity, one test showed image degradation with a 3 minute of arc misalignment.



$\Delta\lambda = 0$ $\Delta\lambda \simeq 25$ mμ $\Delta\lambda \simeq 50$ mμ

Figure 25

Effects of Wavelength Variation

These are three enlargements (13X) of a single pattern exposed with the wedge inteference filter shifted. At the left the filter is correctly positioned near the upper end of the line. The effect of wavelength variation along the wedge filter can be noticed. In the other two exposures the filter has been shifted as indicated. The wavelength shift is larger at the upper end of each of these exposures.

6.6 Effects of Pattern Focal Length Variations

This test was intended to check the depth of focus of the instrument and determine the image deterioration with focus errors. The primary purpose of the test was to obtain data to assist in developing focus control techniques.

The depth of focus has usually been found to be very large. In January 1962, the depth of focus for the 24 inch focal length system was found to be ± .030 inch. The 150 inch system with poor cylinder lenses usually was insensitive to focal shifts of ± .050 inch or more. Recent tests have shown a depth of focus of ± .015 inch for range and ± .025 inch for azimuth. The tests indicated that special focusing techniques would not be needed for the 9015 Processor. Later experience and knowledge has verified this conclusion.

6.7 Signal Integration

This test was intended to study some of the noise effects and signal to noise improvements to be expected in the Processor. These tests were intended to be run after most of the other tests were completed. Some preliminary tests were made in 1963 with a grainy input target. The noise had very little effect on the pattern obtained.

No further specific tests have been performed on this problem. Late in 1964 the bench correlator, Processor, theory, and F101 film quality were perfected to the point that meaningful work could be started, but no conclusive results have been obtained as yet. See also Section 7.8.

6.8 Moving Film Tests

The film drive must meet very rigid requirements in the Processor. It was found to be very difficult to test the film drive in any test other than to run film in the Processor. The final proof of adequacy of the drive was to be accomplished by comparing static and dynamic runs of the same target. Even this test is actually fairly difficult since the tilt angle of the target changes when the film comes to rest for a static test. General experience has indicated that the results of static tests can be repeated dynamically after the tilt and drive ratio adjustments are optimized. A series of test runs in May 1962 show no difference in static and dynamic tests, and a later check in November showed no measurable image smearing on .003 inch wide lines.

Tests made on the new drive system in 1963 indicated that the long time average (a number of revolutions of the drive roller) could be set and maintained to an accuracy of 0.03%. Various tests designed to determine film slippage and/or short term drive ratio variations were conducted. These tests indicated no such problems, but it must be pointed out that these tests were only sensitive enough to detect problems of 1% error or larger. Continued usage of the Processor has not indicated any short term variation of the drive speed or drive ratio.

Section 7.0

STUDIES

7.0 STUDIES

A number of theoretical and experimental studies were made during the four years. Most of these studies were directed toward obtaining solutions or answers to specific problems rather than toward the gathering of theoretical or experimental data.

This chapter discusses many of these studies which required extensive time and/or may be of lasting interest. In some cases additional technical information is included as an Appendix.

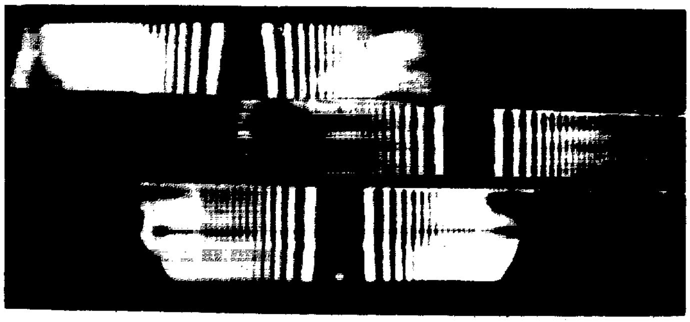
7.1 Early Experimental Work

The first task was to set up an optical system to verify the assumption made in [redacted] and establish an experimental base upon which to build the detailed design. The optical bench described in Section 4.1 was designed and built. Some hand drawn targets and some targets [redacted] were successfully correlated in October 1960 (see Fig. 26). It became clear that high quality input data would be required for quantitative tests. Such data can be generated by a number of interference techniques, and a modified Twyman-Green Interferometer was set up to generate test patterns. The proper patterns were observed, but attempts to obtain adequate photographic recordings of the pattern indicated the need for better equipment and more time than was available.

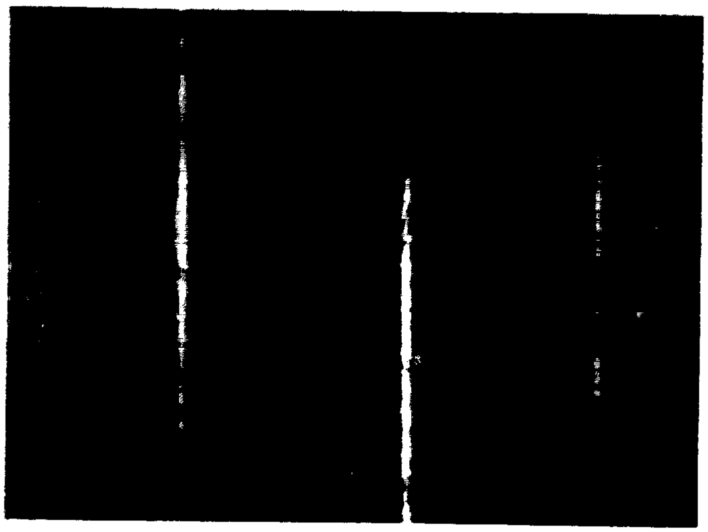
Figure 26

Results of First Correlator Experiments

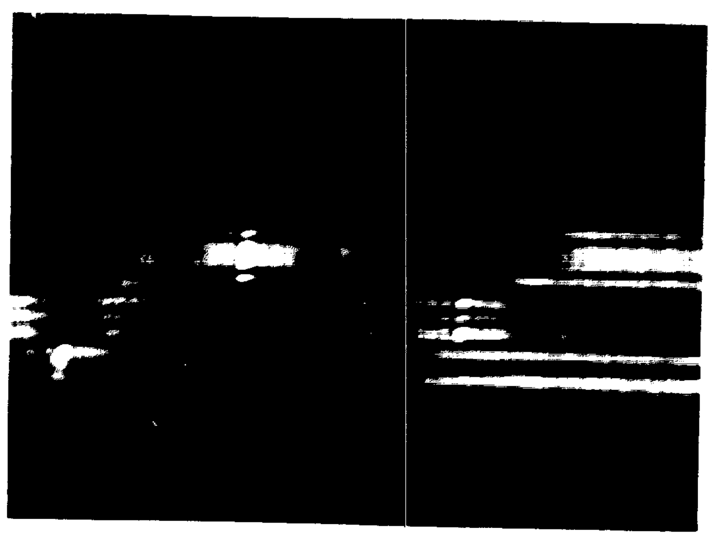
These results were obtained in late 1960. The input patterns are shown above, the correlated images are shown in the center photograph. There was no range imaging in the system. The lower photograph has a cylinder lens to focus range. The images are the bright sections, the zero order and virtual image light spreads into the background seen.



Original Patterns Generated on CRT



Fresnel Images Formed by Patterns



Unfiltered Images Reconstructed with Cylindrical Lens

The experimentation on the bench with the crude targets available confirmed most of the concepts and gave experimental back-up for quantitative theoretical work. A specific example of the value of the bench was the discovery of the data film alignment problem discussed in Section IV(D) of the Processor Final Report and in Section 6.5 of this report.

7.2 Non-Optical Tests

Many tests were performed on portions of the Processor which do not relate directly to its ability to correlate radar data. These included tests on film drives, the optical mounts, the data clock transfer equipment, the carbon arc, and a host of other items. Most of these tests were of transient interest only and are not discussed here. Three of these tests which are still of interest or which played a key roll in the program are discussed briefly.

7.2.1 Mirror Mount

The mounts for the optical elements utilized adjusting techniques which were intended to maintain the adjustment permanently without the use of locking devices. This basic technique was incorporated into a mirror angle adjustment device which used a stiff spring to hold the mirror cell against the adjustment screw. This equipment was breadboarded with aluminum plates and checked with a theodolite. Some modifications were found necessary to eliminate interactions between motions around the two axis. The unit was built* with this design and has performed excellently.

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* A photo is shown in the Processor report on page 12 and Instruction Manual pages 3-23.

7.2.2 Liquid Platen

A test was performed on the liquid platen to obtain information about bubble control and determine the properties of suitable liquids. This test was very helpful and the recommendations still hold. The test report, included as Appendix II, gives a good description of the test results.

7.2.3 Film Drive

A complex breadboard was built to test the film drive. This unit was designed to drive two $9\frac{1}{2}''$ films through suitable rollers with the rubber wheel drive. This unit proved out the basic technique even though it was impossible to devise feasible testing techniques sensitive enough to check the mock-up to full accuracy.

The engineers used the mock-up primarily to check their initial decisions as to bearing sizes, rubber thickness, etc. This unit was used later in testing modifications to the Processor film drives and also to support some tests on the recorder program. In 1963 another simpler mock-up was made to obtain quanatative analysis of the rubber wheel action, this is discussed in the Processor Final Report on page 45.

7.3 Bandwidth and Aperture Weighting

The signal-to-noise ratio and diffraction ring ("side lobe") suppression of an aperture-limited system can often be improved by use of aperture weighting. In the case of the 9015 detail correlator we are interested in weighting both azimuth and range, for extraneous light appears from both dimensions. Since the spatial frequency spectrum of each will be different, an elliptical rather than a circular filter will be necessary. In practice, however, two one-dimensional filters will be placed in quadrature.

The investigations were begun about a year ago. The first finding was that photographic film, on which the filters were made, was insufficiently flat, and impaired the resolution of the relay lens. Obviously optical-quality glass was required for the filter. Another difficulty arose from the granularity of the photographic emulsion, which tended to scatter too much light. Deposited aluminum filters were chosen finally because they offer much better scattering characteristics, although such filters are more difficult to fabricate.

The varying transmission is obtained by depositing the aluminum through a narrow slit which oscillates in front of the surface to be coated. Gradations in density are controlled by the velocity of the slit, since the evaporation rate is constant. A cam of a certain profile is required to drive the slit in the proper manner. Appendix VII explains the process by which the proper cam profile was designed. The cam operates through a linkage which could be adjusted for any desired bandwidth. Unfortunately there was no way of monitoring the deposition while it was in progress, so a trial-and-error method was used. The transmission curve of each filter was traced on a microdensitometer, and the proper correction applied to the next deposition.

Eventually the set of filters seen in Fig. 12 were fabricated. These have approximate bandwidths of 125, 250, 375, and 500 cycles per inch when used on the bench correlator. Filtering in the range direction was foregone for the time being.

7.4 Moving Targets

The detection of moving targets is not a prime function of the radar system, but since the inception of the program it has been thought that moving targets could be located. Certainly the necessary information has been on the data film, for the entire doppler history of a target is recorded while it is in the antenna beam. Not until 1964, however, was a moving target recognized. The detailed theory to determine ambiguity effects and sensitivity has not been investigated, but the following information is of interest.

Several photographs were taken of this target and of other targets subsequently recognized. An investigation of the relevant mathematics was made, the result of which is the report that is Appendix VI. Basically, target motion in azimuth (i.e. parallel path) yields a correlation focal-length different from the environment; and target motion in range results in an azimuth-displaced correlation. A detail correlator can be calibrated so that the velocity components can be readily measured, and a method of so doing is included in the appendix.

A single example will demonstrate the principle. The photographs in Fig. 27 are from film S53. The four shots represent a 3-inch range of focus. In (c) the background seems to be sharpest, while on the highways there are three returns which are out of focus; these are labeled 1, 2, and 3. Note that target 1 is in focus in (a), but blurred on the other three photographs. Similarly target 2 is in focus in (b), and target 3 is in focus in (d).

An attempt was made to measure the parallel velocity components of these targets. The detail correlator was calibrated as suggested in Appendix VI, and the appropriate graphs were constructed. The resulting estimates are as follows:

Target 1: 66 mph
Target 2: 33 mph
Target 3: 33 mph in the opposite direction.

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This is all very approximate, and there is unfortunately no way of verifying the accuracy of the results; but they do seem to be reasonable speeds for cars.

The determination of the perpendicular or range velocity is more difficult. In the 9015 system there are two restrictions on the determination of the range velocity components. The first is associated with PRF of the system, which is 4000 cycles. There will be an ambiguity unless the Doppler shift is less than 2000 cycles. The velocity can be found from the relation

$$\frac{2V_{my}}{\lambda_r} < 2000$$

$$V_{my} < \frac{2000}{2} (.0671) \frac{\text{mi.}}{\text{hr.}}$$

$$V_{my} < 66 \text{ mph.}$$

for unambiguous determination.

The second restriction is more limiting. The bandwidth limitation in the recorder is limited to about 1000 cycles, and an intentional offset of about 300 cycles is used, so a doppler range of minus 1300 to plus 700 cycles can be recorded. This limits the radial velocity to a range of -43 mph to +23 mph.

7.5 Image Analysis

The map films made from the F101 test flights have contained poorer images than were expected. In 1962 and much of 1963 this was largely due to poor system performance, but by early 1964 it became obvious that the lack of image interpretability was not due only to inadequate resolution.

Resolution of 20 feet had been demonstrated, and azimuth resolution was suspected to be half of that, yet no aircraft and few other objects of 100 foot dimensions were recognizable. City and industrial complexes showed much strong return but individual buildings usually were not evident. A major problem limiting the usability of the output map films was and still is that of interpreting the images on the map. The overall process can be considered in a number of steps:

(1) The actual reflection characteristics of a target.

(2) The reproduction of that reflection characteristic on the map film.

(3) The interpretation of the image pattern as the original target.

During 1964 this problem received considerable attention. Topographic maps covering much of the area flown over were procured, and large scale aerial photographs of much of the area were purchased. All useful flights up to S125 were plotted on map overlay sheets and keyed to the topological maps and aerial photos. Some of the facilities are shown in Fig. 28.

In general, it was found that at small scales (1" = 2 miles) the radar picture appears similar to an aerial photograph as illustrated in Fig. 29. At larger scales (1" = $\frac{1}{2}$ mile) the typical differences between the two sensors show up, but the radar picture can still be thought of as an "unusual" photograph. At a scale large enough (1" = 1,000 feet) to show the smallest resolvable element, the radar photo bears little resemblance to an aerial photograph. The illumination, wavelength, and reflection characteristics are now entirely different. In many regions spurious images now dominate

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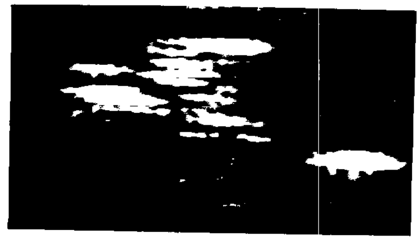

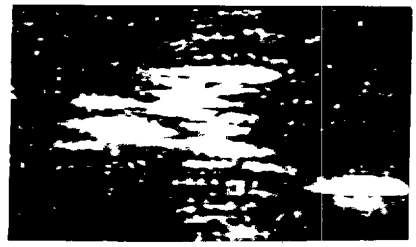

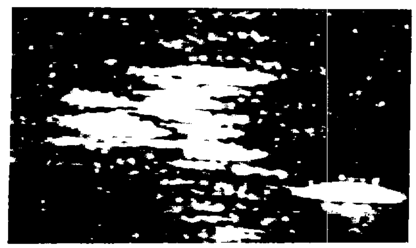

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the contrast is about the same as is seen in Fig. 4).

The difference in the dock area and corner reflector test may be due to the two flights, but it is typical of all experience. Single targets, or well known and simple targets seldom give trouble in determining best focus, while complex targets are confusing and the operator of the correlator is never sure which image pattern is "correct." It should be pointed out that this is the situation as of the end of 1964, it may not be true after further improvements in the equipment or operating procedures are made.

7.6 Color Bandwidth Correction

The optical correlation process is a diffraction phenomena and therefore should ideally be done with monochromatic light. In the 9015 Processor this requirement is approximated by using a narrow band interference filter with a white light source. This creates a spreading of the image due to the fact that the light which is not at the center of the pass band generates out of focus images. The filter was specified to have a very narrow pass band (about 5 $m\mu$) to keep this defocusing effect as small as possible. The pure longitudinal defocusing is adequately small for the system at present.

The wavelength variation also gives rise to a lateral image shift due to the fact that the hologram is squinted (see Fig. 17). This shift causes a large portion of the loss in resolution. This shift can be eliminated in principal by dispersing the input collimated beam a corresponding amount. A study program was initiated late in 1962 to investigate methods of dispersing the beam in the Processor. A technical report on that study is included in Appendix III. The first effort concentrated on finding optical glass combinations which would give a uniform dispersion across the visible spectrum. It was found that the dispersion would vary by a factor of two or more with any reasonable prism, and the basic configuration of the Processor would have to be changed to accommodate the new optical path.

The next step in the study was to investigate a diffraction grating. It was possible to design a grating which would replace the lower mirror, but the question of grating efficiency and the displacement of the output image were open questions. A grating was designed and ordered from the Bausch & Lomb Optical Company. Further analysis indicated that the zero order and second order spectra would overlap the first (desired) order, thus the grating efficiency would have to be very high in the first order to minimize light in the adjacent orders. When the grating arrived in late 1963, it was found to have nearly equal intensity in the zero, first, and second orders, and hence was unusable.

The study was not pursued further since it had been determined that simple solutions were not possible and any other solution would require more expense and Processor down time than was justified.

7.7 Field Curvature*

The most serious optical problem in the Processor is the fact that the best focuses for the azimuth images lie on a curved surface. This curvature causes the azimuth image to be out of focus by as much as one inch at some ranges, depending on the initial adjustments. This causes a loss in resolution. The sources of this problem lie in the relay and cylinder lenses and create a variation in magnification as well as focus. The simultaneous

*The use of this term is not accurate since field curvature usually refers to a non-astigmatic image. However, there are no better short names for the effect and this terminology has been in use so it will be used here.

correction of azimuth focus curvature and magnification variation without altering the range image (which has a flat field) has proven very complex and impractical to implement on the Processor. This problem has been the object of much study and will be described in some detail here.

7.7.1 History of the Problem

Unlike most other difficulties encountered, the existence of a field curvature problem was not suspected until late in the program. The lens system designed was originally pursued until the system was of better quality than required, and the field was predicted to be flat. The computer programs could not handle skew cylinder lens traces, but the apertures were small (f/30), and the field angle was small (5°) so off axis effects were expected to be small. Experimental tests early in 1962 verified that the range image was in focus on a flat field with or without the cylinder lens. Thus there was no concern about the image plane flatness of the Processor. On the other hand, there were many effects on both F101 data and simulated data which would give curved fields for best azimuth focus. All out of focus problems encountered were ascribed (usually correctly) to one or more of these causes.

In the Spring of 1963 some new precision targets failed to give the expected quantitative results across the field, so a simpler target was made and tested. In August, these tests uncovered the curvature of the surface of best azimuth focus.

An analysis of the off-axis effects of cylinder lenses was made to determine the source of the curvature. Approximate first order theory and precision ray traces both verified the existence of the effect. Work began immediately to find a method to eliminate the problem. A new set of interference filters were ordered* and calculations to determine the desired non-linearity were begun. These calculations showed that the technique was not feasible and emphasized the problem of obtaining uniform magnification as well as a flat field. The theory presented in Appendix X was developed, and some quantitative experiments on tilted cylinder lenses were performed.

In January 1964 accurate data was obtained that indicated that the field curvature due to the cylinder lenses should be only one third as great as had been found in the Processor. The experimental Processor had become available and tests on it disclosed that the relay lens was the source of about two thirds of the curvature. A new analysis of the relay lens uncovered an effect of spherical aberration which usually is of little consequence but in the Processor it leads to azimuth focus field curvature. This effect is described below in Section 7.7.3.

The further search for methods to correct the curvature soon lead to the conclusion that there probably were no simple modifications which would solve the problem. A rather extensive program would be required to formulate a solution, and the modifications would probably be costly. These anticipated costs, combined with the uncertainty of anticipated improvements and other project plans, indicated that further effort on the subject was not justified at that time.

7.7.2 Measurement and Effect of Field Curvature

The most accurate data on the field curvature was obtained during the

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*The vendor required six weeks to procure and fabricate the glass before he could coat the filters. They were eventually made linear as originally ordered. Although they duplicated previous filters, they were a better quality and they provided the needed spares.

summer of 1964 [redacted] This data was obtained primarily for the purpose of optimizing the focus and drive ratio adjustments.

Figures 41 and 42 show the magnitude of the field curvature. The data indicated by the solid line was obtained by using a test film covering the entire range swath with identical targets. This test was run with a uniform green interference filters instead of the wedge filter. The added focal shift due to recorder CRT nonlinearity was computed and added to the above data to obtain the curves labeled "net field curvature." In the graphs the net curve is asymmetric, in practice this theoretical situation is not evident and optimum adjustments usually lead to a more symmetrical focus error. The magnification variation is shown in Fig. 43. In practice the Processor drive ratio is set to match the best average magnification. The image broadening due to the magnification-drive ratio mismatch is approximately .001" per percent error. Thus at the best compromise focus the image spread would be less than . 001" over most of the range and would be about . 002" at the extreme edges.

The effect of the curvature on the final map film is not straightforward and not as serious as some of the calculations would indicate. It is clear that the overall radar system cannot achieve the ultimate design goals with the field curvature in the correlator. However, it has not been shown that the present F101 tests would be significantly improved if the present Processor were modified since there are sources of image degradation at the edges of the field in the other components of the radar system. The present adjustments in the system are optimized to give the best overall results, and very little variation of azimuth image quality is noticeable over much

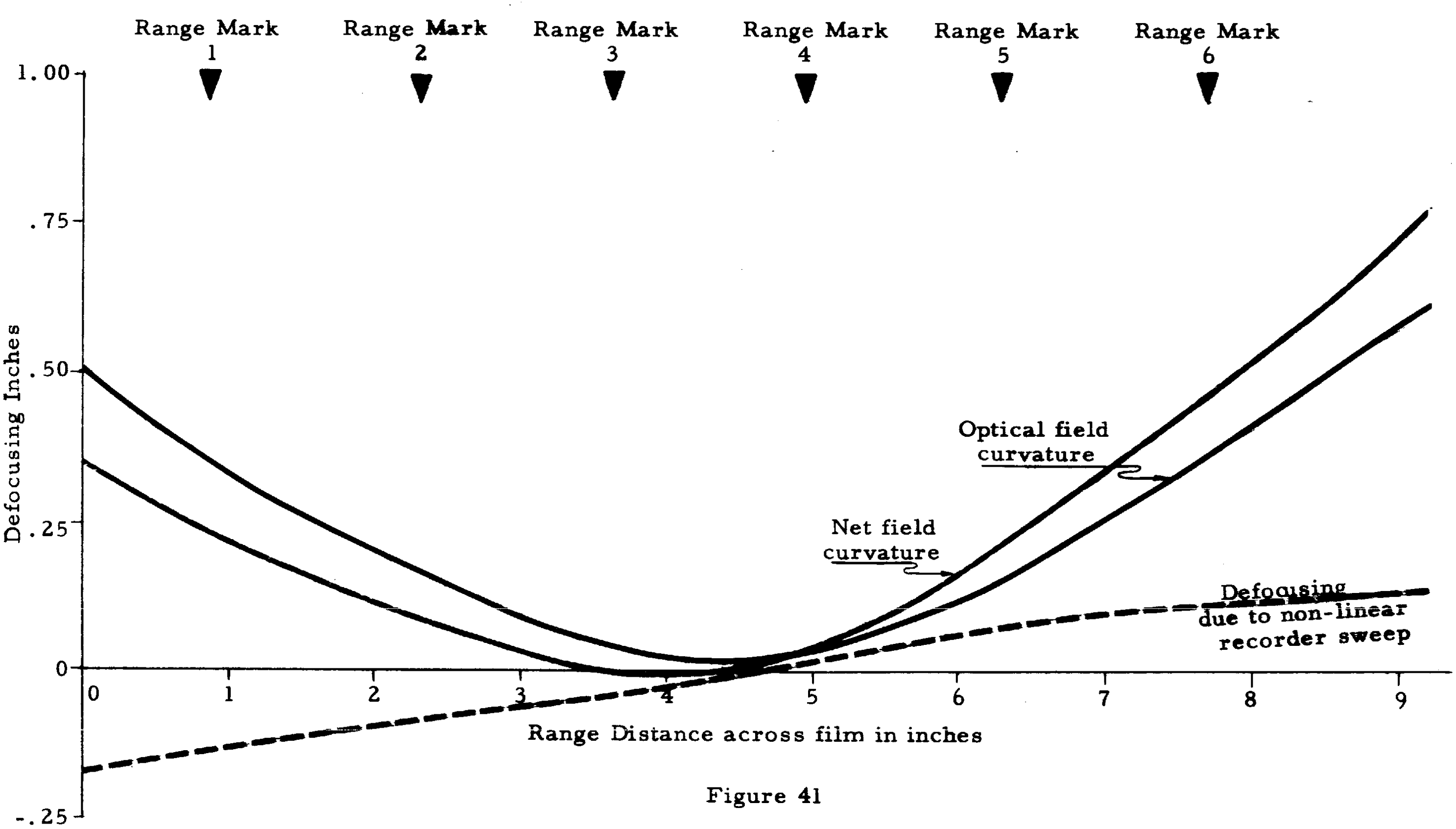

Figure 41

Azimuth Image Field Curvature (Near)

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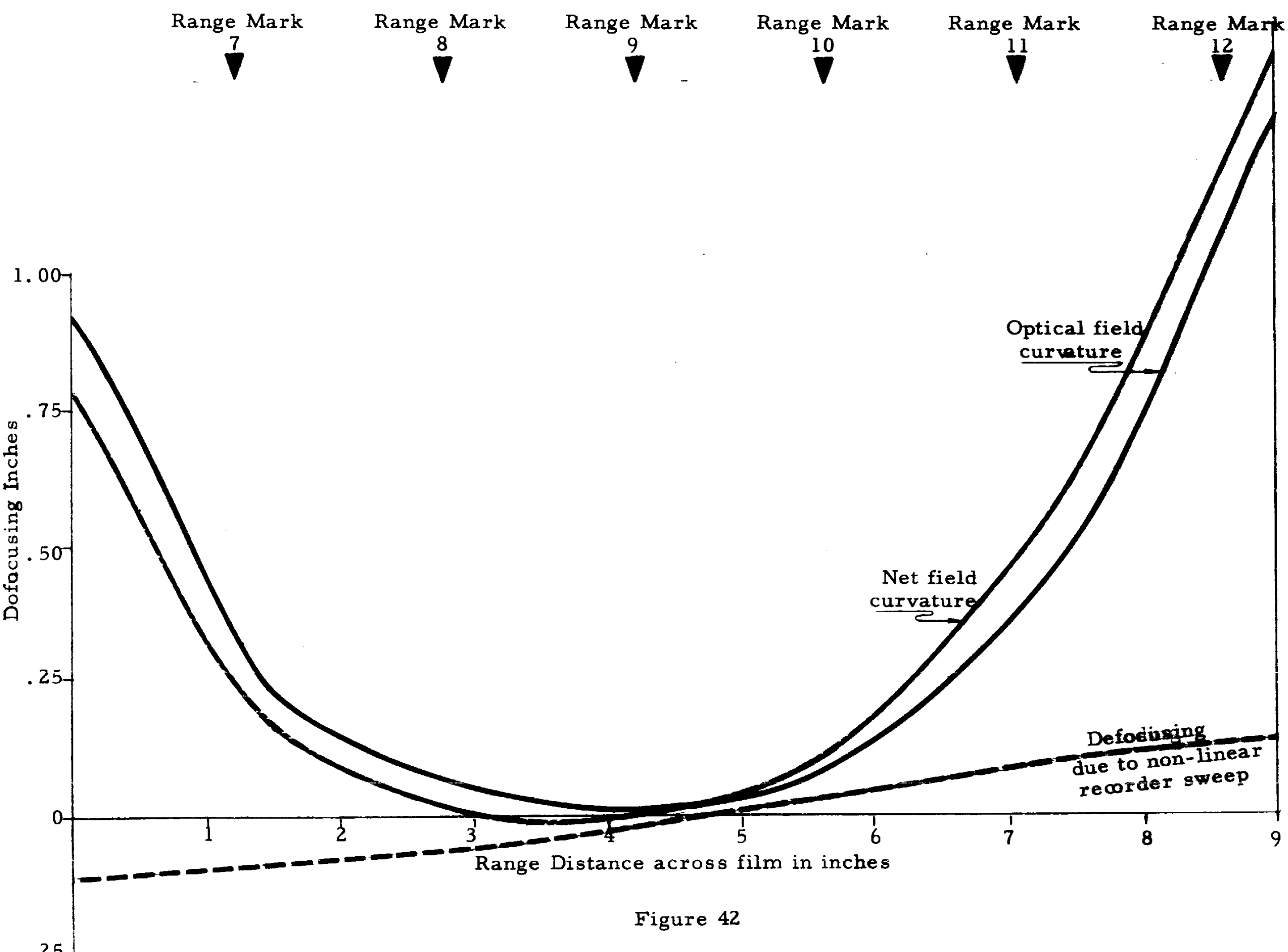


Figure 42

Azimuth Image Field Curvature (Far)

SPECIAL HANDLING

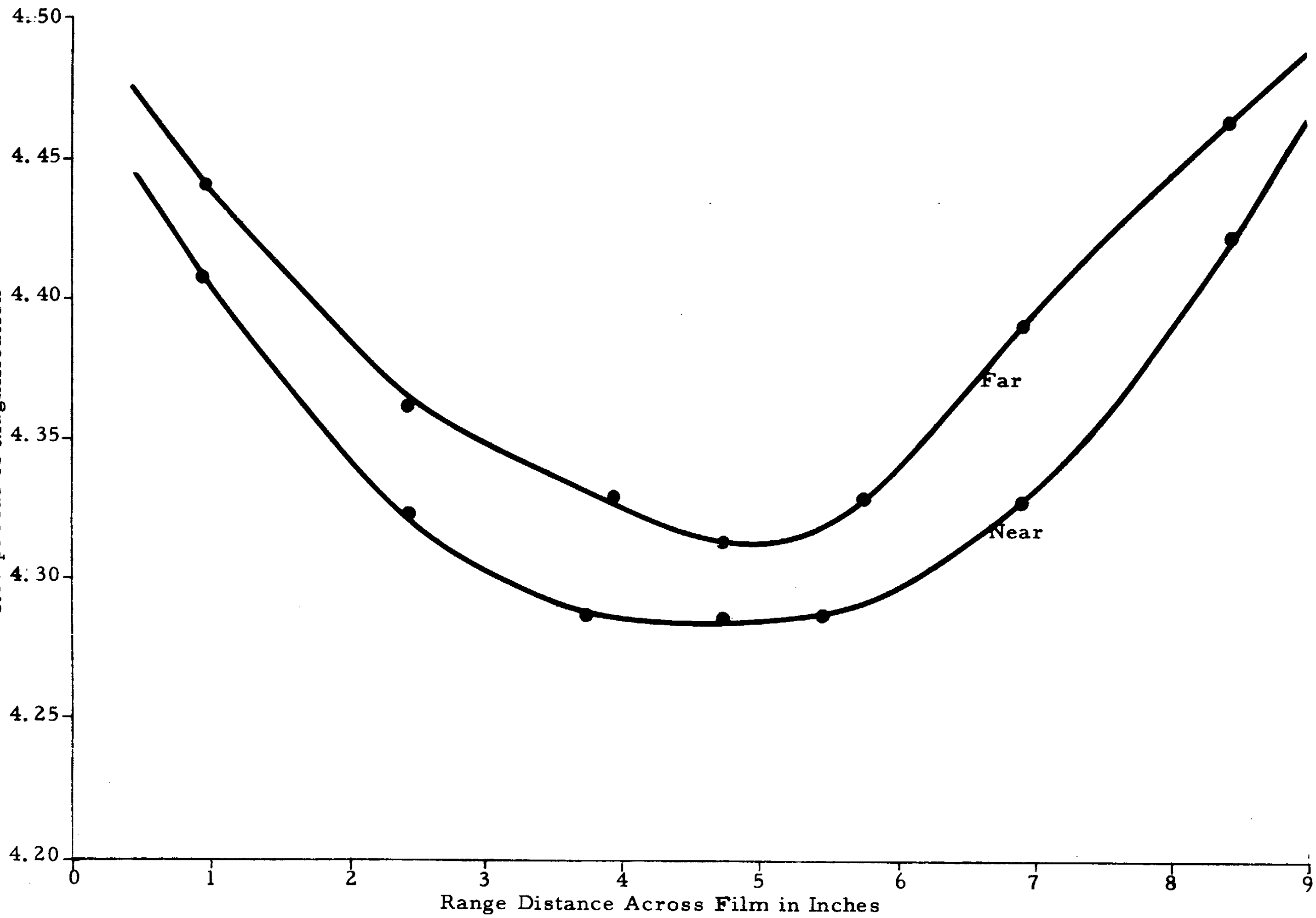


Figure 43

Azimuth Magnification Across Field

of the better correlated maps (for example in Fig. 4).

In cases where better azimuth focus for a particular target is desired, the Processor can be refocused for that area. In addition, the best azimuth focus is obtained on the detail correlator where field curvature is not a problem. Thus an improved Processor would add very little additional capability to the overall development program at this time.

7.7.3 Sources of Field Curvature

The field curvature in the Processor comes from two known sources acting independently, an off-axis cylinder lens effect and a relay lens spherical aberration effect. Both problems were studied in some detail, but both are complex and the theory is not complete.

The curvature due to the cylinder lens can be considered to stem from the fact that the radius of the lens surface is not constant for non-normal cross sections. This results in a shorter focal length for rays traveling in skew planes. In a large aperture optical system this would cause an axial aberration, but in the Processor it creates a field curvature for the azimuth images. The mechanism and first order analysis of the effect is given in Appendix X. A more detailed analysis becomes very difficult since cylinder lenses behave in a complex manner* and there is very little literature on the subject.

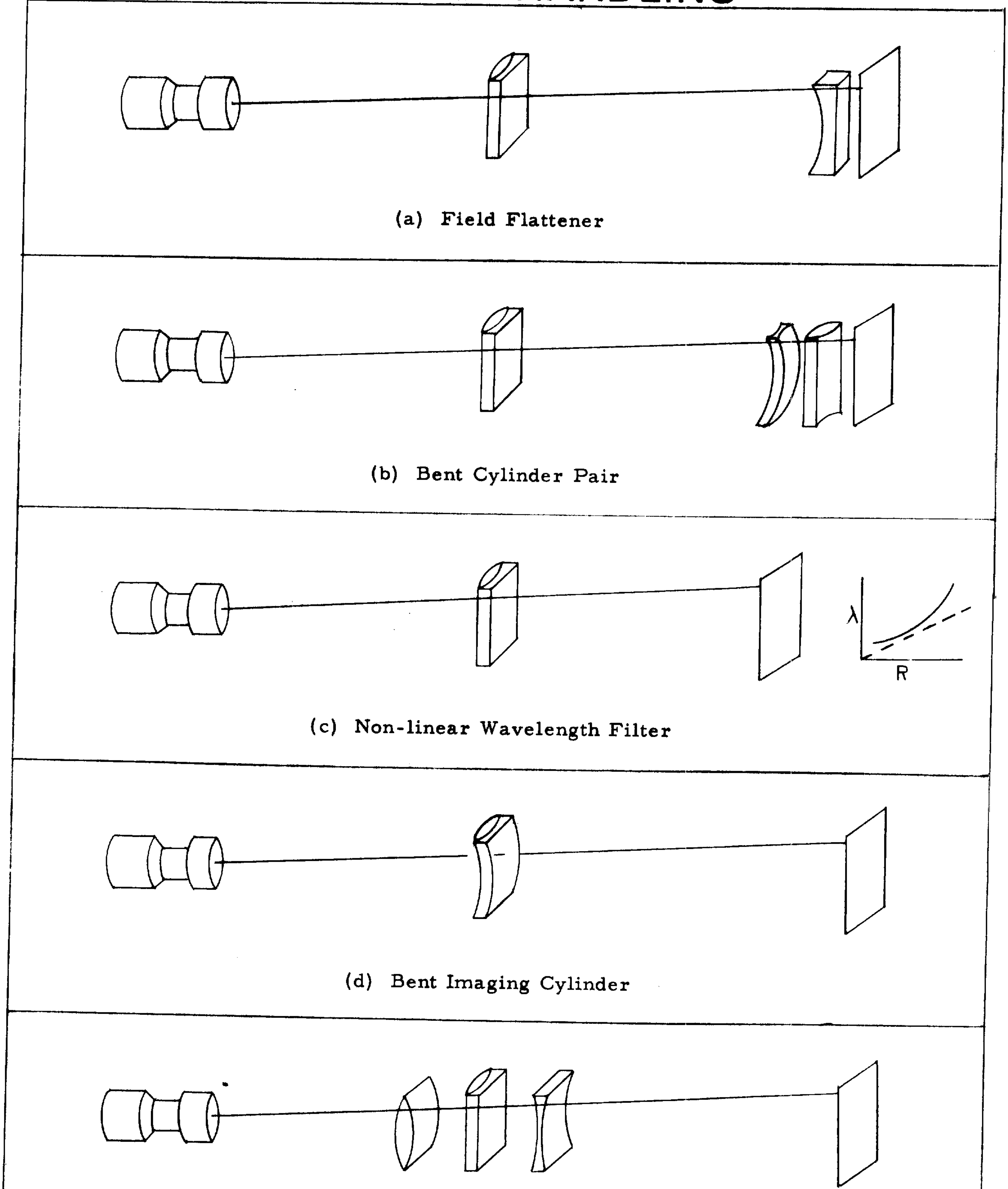
The curvature of the field contributed by the relay lens is a result of spherical aberration of the relay lens as it is used for the azimuth image. This lens is well corrected for the range image, but spherical and astigmatic aberrations depend on the object position and are large for objects near the

*There are 16 first order aberrations instead of the 5 in spherical systems.

lens. Since the relay lens acts as a field lens, the spherical aberration does not degrade the image, and the astigmatism is not an obvious problem since we have only a one dimensional object (the azimuth image formed by the field lens is the object in question). Field curvature is very nearly flat and should be the same for all object points, and recent tests have shown that the field curvature for the azimuth image is negligible. However, field curvature in the relay lens is not the problem. Rather, the fact that images in different portions of the output field are the result of slightly different paths through the relay lens leads to the difficulty. Each of these paths has a slightly different optical power, and thus they form an image in a slightly different plane. In most optical systems these images would be superimposed to form one resultant image which would suffer from normal spherical aberration. However, in the Processor these images are separated in range and thus each is still of good quality but shifted along the axis. This gives rise to the peculiar field curvature noted. This mechanism should have little or no effect on magnification, a conclusion which is verified by experiment.

7.7.4 Field Curvature Corrective Techniques

A number of techniques to improve the azimuth focus have been studied. The effect of shifting the image surface can be readily determined from first order optical theory. The five techniques shown in Fig. 44 have been analized with such theory. The effect of magnification, however, is not readily apparent. In the Processor this is critical since a small variation in magnification causes a relatively large image blur. This effect has been calculated for only one of the techniques described below, in all other cases the magnification will have to be considered as the overall system is designed.



(a) Field Flattener

(b) Bent Cylinder Pair

(c) Non-linear Wavelength Filter

(d) Bent Imaging Cylinder

(e) Collimating Lenses

Figure 44
Field Curvature Correction Techniques

The field curvature in a new design can undoubtedly be kept within the depth of focus. The techniques described below will assist the designer in his work, but the prime source of information will be the results of computer runs which will trace skew rays and check for field curvature.

7.7.4.1 Field Flattener

The common type of field flattener, shown in Fig. 44(a), cannot give complete correction because it would cause the range image to de-focus as rapidly as the azimuth image improved. In a new system the technique could be used by designing a field curvature into the relay lens so as to match the azimuth curvature, a rather cumbersome and difficult technique. In the Processor it would be possible to improve the compromise focus with a field flattener, but it would be impractically thick (one to three inches) and the effect on magnification would have to be checked.

7.7.4.2 Cylinder Lens Pair

A second field flattening device uses a pair of short focal length cylinder lenses as shown in Fig. 44(b). In this technique the converging azimuth beam is collimated and then reimaged onto a flat image surface. To achieve this the negative lens must be located one focal length from the azimuth image surface, and hence is bent to match its curvature. The azimuth image is reformed by adding a positive cylinder with the same numerical focal length. The new image plane is located at the focal distance from this cylinder, which would be straight. These cylinder lenses would have an inherent field curvature themselves, but their design could compensate for that also. The magnification problem is unclear, some simple considerations indicate no variation but the validity of the assumptions is in question. These cylinders would be of a short focal length and be near the output image, so hopefully would not degrade the image.

The theoretical questions left unanswered in the above paragraph were to be checked experimentally if suitable cylinder lenses could be obtained. It was felt to be impractical to manufacture the curved negative cylinder with the correct bow in it, partly because of the need for an expensive accurate design and partly because of the high cost of producing such a complex lens. Therefore the possibility of obtaining plastic lenses that could be bent to shape was investigated*. Two possible vendors were contacted, a firm in Boston which was working on new techniques to make high quality lenses, and a leading plastic lens manufacturer. The techniques used do not give precision optical quality, but sample lenses were fabricated by each firm, both were of grossly inadequate quality and the investigation was dropped.

7.7.4.3 Nonlinear Wavelength Filter

The position of the azimuth focus is influenced by the wavelength filter. The technique of using a wavelength at each point which would cause the image to lie in a flat plane was investigated. In this case the magnification could be determined on a hand calculator. The calculation indicated that the magnification causes a blur which increases about 10 times as rapidly as the out of focus blur is decreased. For this reason this technique was abandoned.

7.7.4.4 Bent Imaging Cylinder

The field curvature introduced by the cylinder lens could be eliminated by causing the beam to pass through the cylinder lens perpendicular to its

*This work was also being pursued for a similar problem in the recorder.

cylinder axis. In theory this could be done by bending the cylinder lens as shown in Fig. 44(d). In this case the lens is the main azimuth imaging lens and hence must be of high quality although of modest curvature. This would have to be manufactured with a torroidal surface, and it is unlikely that such lenses are feasible.

7.7.4.5 Collimating Lenses

The field curvature introduced by the cylinder lens could be eliminated by collimating the beam before it passes through any cylinder lenses as shown in Fig. 44(e). These lenses would be large and would have to be of good optical quality. In concept they should be cylinder lenses, but spherical lenses would probably be used. In a new system, this effect would probably be achieved by the basic layout of the system rather than by the introduction of special lenses.

7.8 Noise and Stray Light

A major limiting factor in radar systems is noise in the output which limits the weak signal resolution. In the system under discussion the Processor acts to increase the "apparent" signal to noise ratio on the data film, and it introduces additional noise onto the output map film. The first effect has not been verified or studied in detail since it has been demonstrated in the overall system and because the equipment and detailed knowledge of the performance of the equipment has not been good enough to support a detailed investigation in the Processor. The noise added by the Processor is introduced by stray light, this latter subject has been studied in considerable detail.

7.8.1 Sources of Stray Light

Stray light was originally recognized as a serious problem. Many steps were taken in the original design to minimize sources of stray light. Experience with the Processor in 1962 and 1963 indicated that the stray light level was low, but not nearly low enough. Some efforts to keep the optics clean and other simple steps were inadequate to reduce the stray light to a negligible level. A more careful analysis of the sources of stray light was needed and was done. The report of that work is included as Appendix IX.

The most surprising results of the study was the discovery that the entrance slit reflection is a serious source of stray light. The companion problem of stopping and eliminating the main zero order image was obvious and a carefully designed black mirror and light tray had been designed for the zero stop*. The study disclosed that the entrance slit creates a similar problem since all the light coming from certain parts of the slit structure reaches the output film. Some steps have been taken to reduce this effect, but the problem is more difficult since the entrance slit is a precision device and cannot be easily modified or redesigned. However, a suitable light trap could be designed and built whenever the cost seems justified.

The stray light due to diffraction around the platen edges was found to be strong but easily blocked. Two other sources, the multiple reflection and mirror scattering, were found to be significant but most solutions would require major redesign and be impractical in the present Processor.

The most serious source of stray light is probably dust and scratches on the collimator and platen glasses. Ideally there should be no such defects,

*See page 33 in Model 9015 Processor Final Report.

but it is very expensive and difficult to eliminate them. The steps that could be taken would be to refabricate some or all of the elements of the collimator, field lens and first element of the relay lens. The possibility of sacrificing some image quality for the advantage of fewer air-glass surfaces in a simple achromat could be considered. A number of platen glasses could be procured so that they could be replaced and resurfaced periodically. The present dust covers are a compromise between accessibility to parts and adjustments, ease of fabrication and installation, and dust prevention effectiveness. This compromise could be reviewed and new covers made if needed. Lastly, further steps could always be taken toward the ideal of a clean room atmosphere.

7.8.2 Effects of Stray Light

The stray light will cause a base exposure on the output map film. Some of this effect will be eliminated on the prints made from the film, but some effects cannot be removed. The effects can be considered in three categories, viz: uniform stray light, large scale variations (center to edge of film) and small scale variations (streaks on the output film). The variation will only be in range because of the film motion.

The uniform stray light will cause a base exposure or fog. The "DC component" of this can be eliminated as described below, but the "AC component" generated by film grain cannot be eliminated. Most of the noise spectrum is below the resolution of the present map films and can be removed by suitable printing devices if desired (it is usually just ignored). However, some of the noise is in the spatial frequency spectrum of the map image, and this results in a loss in signal to noise ratio that cannot be recovered in subsequent printing or viewing procedures.

The proper printing exposure will normally compensate for a uniform fog (the fog can be considered as an additional neutral density filter in the printer). If the stray light has large scale variations, the compensation should vary and hence dodging techniques would be necessary for complete correction. The print will normally be high contrast (the output film has a low contrast) and may need dodging to compensate for image exposure variation. The need to compensate for stray light thus requires more effort to produce a high quality print.

The small scale variations will appear as streaks on the output film. This will usually be caused by dust or other scattering sources near the input platen which are imaged in the range direction. The seriousness of the problem is best evaluated by examining the output map film or print.

7.9 Film Response

The system response and performance is a function of the characteristics of each component in the system. The response of the films, especially the data film, received a good deal of attention in the earlier phases of the project. In photographic nomenclature, the response is usually included in the slightly broader field of sensitometry.

The topic of film response was considered in the early design phases of the project. There was serious concern that the data film could not have the correct response and still cover the wide dynamic range anticipated. This would require strong signal limiting in the electronics and possibly the duplication of the data film onto a print film before good correlatable data could be obtained. The theory (or the application of the theory) was complex and the subject of best film sensitometry was left to be determined by experiment.

The first flight films were too poor to provide adequate data for this investigation. The film (Kodak Aerial Tri-X) was processed normally, and seemed to give as good results as could be expected. Early in 1962 some better flight films were duplicated at various contrasts and correlated. The results of this test indicated that the contrast on the data film made relatively little difference (other than reducing the dynamic range). This result was in general agreement with day by day experience.

The reason for this lack of difference with film response seemed to be partly that the coherent radar system is not as sensitive to this factor as simple theory would indicate, and partly due to other over-riding sources of image degradation — primarily phase errors due to aircraft motions and nonlinearities introduced by signal limiting. The lack of accurate experimental information indicated the need for a separate study. This was done by an engineer who had worked in the coherent optics field for some time, his report is included as Appendix XII. The findings indicate that the best results would be obtained on the toe of the D-log E curve, and that the sensitometry used is not optimum from the standpoint of eliminating ghost images.

The general subject of system response was not intensively studied during the period of mid 1963 to late 1964. It was assumed that other problems would have to be solved before sensitometry would be an important factor. During this period the film type, exposure and developing characteristics have been set primrily on the basis of dynamic range, repeatability, and previous experience. Continued experience with the system has brought about increased understanding of the problem, and it is now recognized that the function which should be linear is the square root of coherent transmission as a function of input voltage to the recorder.

No films can meet this requirement exactly, but all films come close over a limited range. It is likely that this subject will soon require more attention, especially if some tests on radar response currently in progress give the anticipated results.

In 1965 a study was made of film selection and chemical processing. This indicated that some new films would give improved noise characteristics. A report will be issued in July 1965.

7.10 Cone Lenses

For monochromatic correlation of coherent side looking radar data the optical system will have to have varying power in the range direction as is described in Section 9.0 and Appendix XIII. One conceptual solution to this requirement is to use a cylinder lens with varying power along its length, i.e. a cone lens. In the fall of 1963, Itek's optical shop made a cone lens on an in-house research program to determine the feasibility of such a lens. The program developed the necessary information to establish specifications, feasibility and measurement techniques. It was concluded that such a lens could be built if needed.

Section 8.0

PROGRAM SUPPORT

8.0 PROGRAM SUPPORT

8.1 Introduction

Itek has assisted in the system test program by taking the responsibility for processing the films produced by the airborne equipment. The prime function has been to correlate the data films to produce map films.

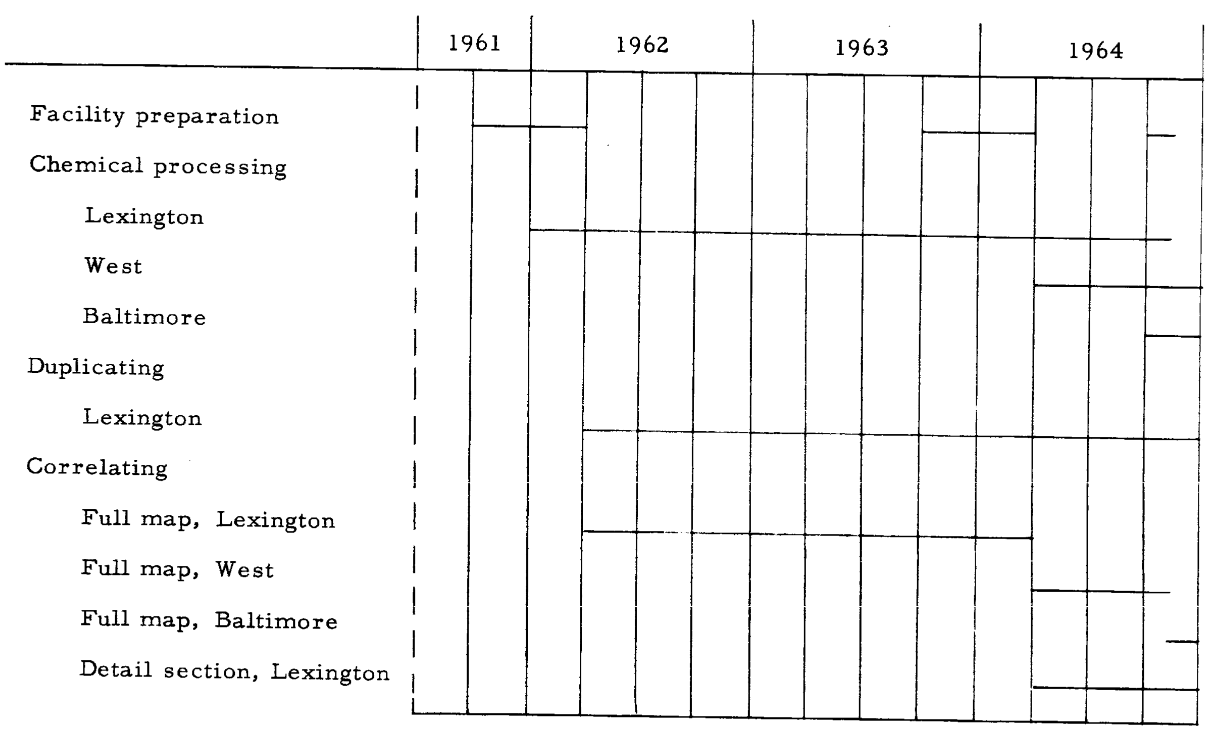
Conceptually the developing and correlating of F101 flight test films would be a routine service, but the intimate relationships between the Processor, radar, and test conditions required an engineering effort to produce the best test results and technical information. The fact that the Processor was a new development and was undergoing subsystem testing and modification indicated the need to keep it with the optical and photographic personnel at Itek in Lexington until much of that work was finished. Table 7 shows the schedule of the major Itek effort for the flight test phase of the program.

The flight tests are made by the Westinghouse Corporation from their plant at the edge of Baltimore's Friendship Airport. The airborne equipment is mounted in an F101 aircraft, and has been flown on over 100 data collection flights along the east coast, primarily over northern Virginia, Maryland, and some of the coastal cities.

The radar is designed to mount in the final vehicle, and it was anticipated that tests would be run with it in 1964. The move of the Processor to the west in 1964 was made to provide close support for those tests. At the present time,

Table 7

Flight Test Support



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the emphasis is on work associated with the F101 tests, so the Processor has been re-located in Baltimore.

8.2 Procedure

The data film was exposed in the airborne recorder during the F101 flight. A flight number was assigned to the film (see Table 8) and it was shipped to Itek via customer approved route. The film was chemically processed, two duplicates were printed, and the data film was correlated. The correlated film was developed and duplicated. One duplicate of each film was returned to Westinghouse via the same route. The actual schedule of events varied somewhat depending on the test and other work in progress, but under normal procedures the flight was run in the afternoon, the data film duplicate was shipped from Itek the next afternoon, and the map film was shipped in the evening or on the following day. Technical information concerning specific problems was usually conveyed by telephone in less than 24 hours after the flight.

The procedures were altered when the Processor was moved to the western site and the various steps were performed at various locations. At the present time all operations for the full map production are in Baltimore, duplicates are sometimes sent to Lexington for further analysis on the experimental Processor by Itek engineers.

The exchange and documenting of information was informal for the early flights, but as the magnitude of the program grew a number of forms were developed to help in the communication problem. The forms in current use are included in Appendix XI. An additional sheet containing information about the overall map quality and specific test results is also prepared and

Table 8

F101 Flight Film Code Numbers

First letter is S (assigned by Westinghouse)

Next number is flight number (assigned by Westinghouse)

Number in parenthesis is run number (assigned by Westinghouse)
(run number is not used if only one run is duplicated or correlated)

All films generated at Itek will have further information:

-D	Duplicate
CN	Correlated, near range
CF	Correlated, far range

STAT

BN, BF	Correlated at Baltimore

The next number indicates which duplicate or which correlation.

Additional D's indicate further duplications.

Hypothetical example:

S8	Flight test #8, original data film.
S8D8	Eighth duplicate of S8.
S8D8D8	Eighth duplicate of S8D8.
S8CN8	Eighth correlation. Used S8 near range.
S8D8CN9	Ninth correlation. Used S8D8, near range.
S8(8)CF10	Tenth correlation. Used run 8 of S8 far range.
S8(8)CF10D8	Eighth duplicate of S8(8)CF10.

distributed.

8.3 Flight Test Results

This section will be a brief review of the results of the flight tests. This topic has been of considerable interest to the Processor program because it relates to the overall effort and also because it is one of the chief sources of data for testing the Processor and correlation techniques. Unfortunately, the F101 installation is very susceptible to wind directions and air turbulance, a factor which reduces considerably the usefulness of the data obtained.

The first data film received was flight S5 flown on March 13, 1962. This flight plus the two that followed provided very little weak data. Since it was felt that this was due to a lack of power it was decided to fly at a lower altitude. A change in the vehicle velocity compensated for the change of altitude and made it practical to use the same parameters as the higher altitude. The only variation was a change of slope in the hologram focal length vs. distance curve which could be compensated for by using the five inch interference filters at the output. The low level flight had the advantage that more passes could be made over one target area on the same flight.

The first flight which provided good data was S11 made on May 9, 1962. This film was correlated sixteen times during the month and provided the first opportunity to study the effects of adjusting various components of the Processor. Such things as slit width, the amount of squint, rotation of the slit and cylinders, mirror position, filters, focus of the various lenses, drive speed were changed and exposures made both dynamically and statically.

The next few flights provided little data. In the meantime, the new cylinders were received and installed in the Processor. S33 made in November provided the first fair low altitute map. This was also run under varying conditions. S34 received January 3, 1963 had one good run and this also was run many times. S37 was good also and run sixteen times during January and February 1963 as was S40 during the next two months.

Since the power had been improved the next series of flights were at the higher altitude. The first fair map was on S46 and the first good map was S62 made in June 1963. This also was run many times. An attempt was made to test the effects of photographic parameters (different product gammas) on duplicates of S62, but the duplicating printer could not maintain the necessary tracking accuracy.

In October 1963 the airborne equipment was more reliable and during the final three months of 1963 provided the best and more consistent data to date (i.e. 12/31/64) By this time the Processor was operating well and a good output map film could usually be made on the first run.

A new set of airborne equipment installed in December 1963 gave generally poor results until May when S107 was run. This film resolved corner reflectors separated by 10 feet. Many of the ensuing flight tests were designed to study specific problems, and only a few are good overall map films. S119 gave a very good overall map (Fig. 30), while S123 resolved corner reflectors separated by 5 feet (see Fig. 40).

8.4 Field Support

The continuing technical problems on the program indicated that Itek should continue to provide an engineering capability for flight test support after the Processor was moved from Lexington. It was expected that the flight test program would shift to the final vehicle, so arrangements were made to provide field service [redacted] The move was originally expected early in 1963, and during that year the Processor was ready to ship on a month's notice*. Additional personnel from Itek's Field Support Group in Palo Alto, California were trained on the equipment, but schedule changes prevented their use in the field**. STAT

In 1963 the facility requirements [redacted] were drawn up. A floor plan was made for placement of the Processor, fifteen-foot optical bench, light table, sink, storage cabinets and work tables. This drawing also included power and environmental requirements. A separate drawing gave the location of the intake and exhaust ventilation for the Processor and carbon arc. A room $19\frac{1}{2}$ feet square was allotted for the Processor and additional space was provided in an adjacent office area. These rooms were constructed in the Fall of 1963, during which time the Itek Field Engineer made two trips to coordinate the work and become acquainted with the facilities [redacted] In general the facility was satisfactory except for a low humidity problem and the dust brought in by the ventilation system. The support services were very good. STAT STAT

The equipment was shipped from Lexington [redacted] on March 18-20, 1964. A government aircraft was used, and the Field Engineer accompanied the equipment. Some of the ventilating systems had to be completed after the Processor was on location, and the unit was checked out and processing data films by the end of April. STAT

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* Modifications to the Processor were designed so that they could have been installed in the field if necessary.

**The technician trained on the recorder program did provide field support.

The two field personnel have processed data films, provided technical liaison with the Westinghouse engineers, and run tests on the Processor since that time. The most accurate data on field curvature and magnification variation was obtained during the Summer.

Early in the Fall the possibility of relocating the Processor in Baltimore was raised. Again plans were made, the equipment was crated, and was moved across the country. The unpacking and check out of the Processor took only a few days, and a number of flight films were run in December.

8.5 Note Added in 1965

During the first five months of 1965 the two field personnel and the Processor have been working at the Westinghouse plant in Baltimore. About 30 more flight films have been processed, and much attention has been devoted to improving the general appearance of the films. The Westinghouse and Itek engineers reinvestigated possible improvements to the Processor, but most were found impractical on the same grounds as have been discussed earlier in this report.

8.6 System Support

The Itek Corporation has a system support responsibility in addition to the basic Processor program. This system effort is a part of the main 9015 project and is on an "as required" basis. Personnel on the recorder project (Itek 9134) also contributed to the system effort.

Itek system support amounts to contributing optical capability to the overall system design and evaluation done by personnel from Itek, Westinghouse, [redacted] the government. Topics such as frequency bandwidths, motion compensation, resolution budgets, and critical hardware problems were discussed in detail.

In addition there has been continued contact by telephone and individual visits. Many questions pertaining to the overall system have been investigated experimentally or theoretically. Most of the work was of an informal nature and the results of tests reported directly to the engineers involved. One example of this effort concerns a request by Westinghouse for Itek to examine flight films S105 and S106 to determine the cause of poor resolution at the edges of the correlated map films. It was found that the input data quality was poor and the trouble was traced to a burned out tube in the focus modulation circuit in the recorder. This was corrected and the next flight, S107, gave good results across the whole field.

A third general area of system work has been in the planning of further work and writing of proposals, most of which were written by individual project teams but contained ideas contributed by all groups. The Westinghouse and Itek personnel also cooperated on a number of proposals and one study for other coherent radar systems. These efforts were very fruitful in stimulating new ideas and concepts which related to this project.

Section 9.0

NEW SYSTEM

9.0 NEW SYSTEM

New knowledge and new devices have opened the way to improved processors. These advances are being pursued by other organizations in the coherent radar field and Itek has interpreted these advances in terms of the present system. A summary of the new possibilities is given in this section and in Appendicies XIII and XIV which are the correlator sections from a recent proposal submitted to Westinghouse.

The most dramatic change has been brought about by the development of the laser. This light source is ideally suited to the correlation process and allows major advances in many aspects of the equipment. The bench correlator has been able to take advantage of the laser to achieve high resolution and high light levels. A new detail correlator recently proposed* makes use of the laser, see Section V(2) of Appendix XIII.

The experience with the bench correlator has indicated the advantages of visual observation of the correlated image. The light level is now high enough for comfortable viewing at adequate magnification for a correlator viewer. This type of device, termed a detail correlator, has the inherent advantage that the operator can vary the correlator adjustments and observe the results, thus he can extract more information from the data film than is

*Two detail correlators were built during the first five months of 1965. One was a simplified version of the bench correlator, the other was a console unit.

possible when only one map film is made with routine adjustments. The simple detail correlator has no range compensation, a limitation that is not serious in this unit. For small area photographic records, a small amount of range compensation could be included rather easily if desired.

The detail correlator described in Appendix XIII is designed to be built for minimum cost. It does not have many features and conveniences that are usually built into Photointerpretation film viewers. It is anticipated that high quality viewers incorporating automatic film drives, mensuration equipment, range compensation, large screens, etc. will be of great value in an operational system, but the proposed unit is considered to be adequate to lead the way for such sophisticated viewers.

The laser is also the ideal source for a full film width Processor. A new Processor using a laser light source will produce output map film at a much faster rate, the time to process a full run will be cut from hours to minutes. In addition, the laser eliminates the resolution loss due to a finite wavelength band and thus will give better azimuth resolution.

The experience gained on the 9015 program has indicated that there are a number of problems which are inadequately solved in the present Processor It is felt that all the problems can be solved on the next unit if (a) suitable development work is done on a few specific items, (b) the unit has adequate flexibility for making minor modifications, and (c) no attempt is made to make the unit compact of lightweight at this time. The unit described in Appendix XIII is felt to meet these requirements. The flexibility required for (b) also allows for the unit to be started before complete results are obtained on the breadboard units for part (a).

Section 10.0

DOCUMENTS

10.0 DOCUMENTS

A number of reports and documents have been written on the project. These are listed in Appendix I and a few are described briefly below.

10.1 Final Report, Model 9015 Processor

This was published in May 1964. It describes the Processor and sketches the basic theory of the unit. Since the Processor constitutes over half of the entire program, that report is considered to be a separate section of this final report. It is referenced and updated in Section 2.0 of this report.

10.2 Final Report, Test and Simulation Program

This report was first published in April 1963. Much of the data was soon out of date and so the report has been re-written and incorporated into this report, primarily in Sections 5.0 and 6.0.

10.3 Operational Manual

An operational manual was written in February 1963. It was published in two sections, an unclassified portion describing the mechanical and electrical devices and procedures, and a classified addendum which contains optical adjustment information. Subsequent modifications have not changed the operation very much, information relating to those changes are kept with the log books. The first portion of the manual contains information which may be of interest to people other than operators and is therefore included as an appendix to this report (Appendix IV).

10.4 Monthly Reports

A short progress report has been submitted monthly. For a period of about one year the report also contained some technical results from the Test and Simulation program.

10.5 Drawings

A set of drawings has been maintained on the Processor. Time limitations required some shortcuts (e.g. using layouts for assembly) during the Summer of 1961, but the deficiencies have been corrected and the drawing file has been maintained up to date with all the modifications.

A set of reproducible drawings were made for delivery in 1961, but it was requested that instead of their being sent, the drawing file should be continually updated so that the reproducible set could be remade and delivered later. A new set has now been made and delivered.

10.6 Spares

The spare parts program was completed and parts delivered with the Processor.

The list of recommended spare parts is included as Appendix V.

10.7 Acceptance Tests

A preliminary acceptance test was run in November 1961. A final acceptance test of the Processor and all associated equipment (i.e. the optical bench units) was held in December 1963. No new equipment (other than additions to the optical benches) has been built since that time.

Section 11.0

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

11.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

11.1 Summary

For the past $4\frac{1}{2}$ years Itek has worked in conjunction with [redacted] STAT

STAT [redacted] the Westinghouse Corporation on a High Resolution Coherent Radar system. Itek has contributed in a number of areas including system support, field support, and the development of the film handling equipment. One of these equipments, the recorder, was built on a subcontract to Westinghouse and is discussed elsewhere (Project 9134 reports). The other unit which was designed, built, improved and operated is a ground based Data Processor. This Processor and the work associated with it (Itek Project 9015) is the subject of this report.

The Processor was originally built on an accelerated schedule in 1961. It incorporated some new techniques and had to achieve very high performance in some respects. The unit performed very well in most respects, but did not work as well in some other respects. The Processor design was based on the use of a white light source and a "rainbow filter" using the then best available components. Since that time the invention and production of lasers has made the monochromatic design the best. During 1962 and 1963 the unit was improved as some defects were corrected and as our knowledge of the correlation process and astigmatic optics improved. The Processor was used constantly during this time to support the F101 test program and to perform various tests and investigations on the correlation process.

During the last two years much of the effort was devoted to certain basic problems of correlation, astigmatic optical systems, and coherent radar data utilization. A bench correlator and test equipment was built and studies were made. Some improvements were made to the Processor, but most modifications were found to be impractical on the present unit. These studies are discussed in this report (primarily in Section 7.0) and the potential improvements are incorporated in a proposed new design covered in Section 9.0 and Appendix XIII.

The Processor is a functioning unit even though it has some problems and limitations. It has produced many hundreds of feet of high resolution radar data, much of which is reported to be as good as or better than any other radar data produced by advanced systems.

11.2 Recommendations

11.2.1 9015 Processor

At the present time it is recommended that the present Processor, bench correlator, and accessory equipment continue to be used as required to support the F101 test program. This equipment is considered to be adequte for test purposes, although it is inadequate to produce a good looking full quality output map film.

11.2.2 Improved Processor

Whenever the capability to produce a full quality output film becomes needed, it is recommended that a new correlator be built. Such a device has been proposed, its chief features are outlined in Appendix XIII.

11.2.3 Further Studies

The overall field of coherent optical data processing is rapidly expanding and a great deal of work is yet to be done. Continuing studies on almost any aspect of the problem would be worthwhile if adequately funded and staffed. However, for the present situation it seems that the recommendations should be directly related to the development of a new correlator to replace the 9015 Processor when and if it is needed. Most of the preliminary studies for such a unit have been done, and the next step would involve rather comprehensive programs in one of the two major problem areas, namely film drives and astigmatic optical systems. Either or both of these efforts would be directed directly toward the specific design outlined in Appendix XIII, and should culminate in a prototype of the drive and servo mechanism and/or a working optical system. Each of these programs would amount to about one third of the complete program to construct the Processor described in Appendix XIII.

Two other areas need improvement if full use is to be made of high resolution coherent radar, a better recorder and better interpretation techniques. It is believed that both areas are being investigated elsewhere, but each should receive specific attention on this system if it is pursued further.